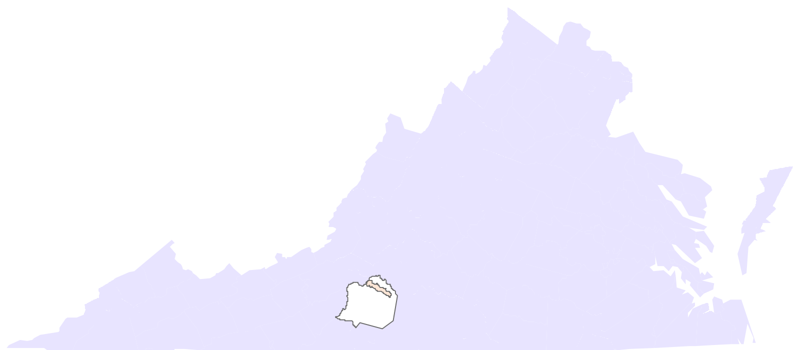
Fecal Coliform TMDL

(Total Maximum Daily Load)

Development for

Gills Creek,

Virginia



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EXECUTIVE SUMMARY

Fecal Coliform Impairment

Gills Creek was placed on the Commonwealth of Virginia's 1996 303(d) List of Impaired Waters because of violations of the fecal coliform bacteria water quality standard, and remains on the 1998 303(d) list. Based on exceedances of this standard recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the stream does not support primary contact recreation (e.g. swimming, wading, and fishing). The applicable state standard specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 1,000 colony forming units (cfu)/100 milliliters (ml) (Virginia Water Quality Standard 9 VAC 25-260-170). Alternatively, if data are available, the geometric mean of two or more observations taken in a thirty-day period should not exceed 200 cfu/100 ml. A review of available monitoring data for the study area indicated that fecal coliform bacteria were consistently elevated above the 1,000 cfu/100 ml standard. In TMDL development, the geometric mean standard of 200 cfu/100 ml was used, since continuous simulated data was available.

Sources of Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include wildlife; grazing livestock; land application of manure; land application of biosolids; urban/suburban runoff; failed, malfunctioning, and operational septic systems; and uncontrolled discharges (straight pipes, dairy parlor waste, etc.). To account for un-quantifiable loads from known wildlife species, a background load was applied to all land segments equal to 10% of the total wildlife load quantified.

Water Quality Modeling

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and perform TMDL allocations. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model.

Thirty-minute flows from the USGS station (#02056900) on the Blackwater River were transformed using regression analysis of flows at the VADEQ station 4AGIL008.30. The transformed flows were used to calibrate hydrologic flows for the Gills Creek watershed in the HSPF model, thereby improving confidence in computed discharges generated by the model. The representative hydrologic period used for calibration ran from October 1, 1994 through September 30, 1998. The model was validated using daily flows recorded at the same gaging station from October 1, 1980 through September 30, 1981 and from January 1, 1991 through September 30, 1994. The time periods covered by calibration and validation represent a broad range of hydrologic and climatic conditions and are representative of the 20-year precipitation and discharge record. (For purposes of modeling watershed inputs to in-stream water quality, the Gills Creek drainage area was divided into nine subwatersheds.) The model was calibrated for water quality predictions using data collected at VADEQ monitoring stations between January 1993 and December 1995, and validated using data collected between January 1992 and December 1992. All allocation model runs were conducted using precipitation data from January 1992 through December 1996.

Existing Loadings and Water Quality Conditions

Wildlife populations and ranges; biosolids application rates and practices; rate of failure, location, and number of septic systems; pet populations; number of cattle and other livestock; and information on livestock and manure management practices for the Gills Creek watershed were used to calculate fecal coliform loadings from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also, represented in the model were direct nonpoint sources of properly functioning septic systems located within 50 feet of a stream, uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock.

Contributions from all of these sources were represented in the model to establish existing conditions for the watershed over the representative hydrologic period (1992-1996). The HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

Load Allocation Scenarios

The next step in the TMDL process was to adjust loadings to existing conditions (i.e. 2001), and determine how to proceed from existing watershed conditions to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's fecal coliform standard does not permit any exceedances of the standard, modeling was conducted based on 0% exceedance of the 200 cfu/100 ml geometric mean standard and a 5% margin of safety (MOS), resulting in a target concentration of 190 cfu/100 ml. Scenarios were evaluated to predict the effects of different combinations of source reductions of final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target with 0% exceedance. Periods of low flow were critical in terms of water quality. The set of scenarios explored pointed to the importance of reducing direct deposition loadings to the stream. The final load allocation scenario (i.e. the TMDL source reduction) required a 100% reduction in uncontrolled discharges, a 100% reduction in direct deposition to the stream by livestock, and an 95% reduction in direct deposition by wildlife.

Margin of Safety

In order to account for uncertainty in modeled output, a margin of safety (MOS) was incorporated into the TMDL development process. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. The purpose of the MOS is to avoid an overall bias toward load allocations that are too large for meeting the water quality target. An explicit MOS equal to 5% of the targeted geometric mean concentration of 200 cfu/100 ml was used in the development of this TMDL. As a result, allocations were made based on a modeled 30-day geometric mean not exceeding 190 cfu/100 ml.

Recommendations for TMDL Implementation

The goal of this TMDL was to develop an allocation plan that can be met during the implementation stage. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act states in Section 62.1-44.19.7 that the "Board shall develop and implement a plan to achieve fully supporting status for impaired waters". To this end, funds will be sought to follow this TMDL development with establishment of a monitoring scheme and development of strategies for a staged implementation plan for restoring the water quality of the Gills Creek impairment to levels identified in this TMDL.

The TMDL developed for the Gills Creek impairment provides allocation scenarios that will be a starting point for developing implementation strategies. Modeling shows that periods of low flow are the most critical for water quality. This result points out the need to reduce direct deposition of fecal coliform bacteria to the stream. Additional monitoring aimed at targeting these reductions is critical to implementation development. Bacterial source tracking to identify sources of contamination in the impairment area will contribute greatly to the implementation effort. Once established, continued monitoring will aid in tracking success toward meeting water quality milestones.

A staged implementation plan is essential to the process of restoring water quality. The goal of the first stage is to foster local support for the implementation plan. The model scenario developed for the first stage included a 100% reduction in uncontrolled discharges and a 90% reduction in direct deposition to the stream by livestock. The first stage of the implementation represents preliminary steps in achieving the final allocation. A staged implementation plan is necessarily an iterative process. There is a measure of uncertainty associated with the final allocation development process. Continued monitoring can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

Also critical to the implementation process is public participation. Permitted point sources provide a limited contribution to the overall water quality problem. Nonpoint direct deposition to streams is the critical factor in addressing the problem. These sources cannot be addressed without public understanding of and support for the implementation process. Stakeholder input will be critical from the onset of the implementation process in order to develop an implementation plan that is truly implementable.

Public Participation

During development of the TMDLs for the Gills Creek watershed, public involvement was encouraged through public and semi-public meetings. The first, semi-public meeting included members of participating agencies and outlined the development process and subsequent meetings. Two public meetings were held for the public at large, involving citizens from the Gills Creek watershed. A basic description of the TMDL process hydrologic calibration, pollutant sources, and the agencies involved were presented at the first of the two public meetings. The final model simulations and the TMDL load allocations were presented during the final public meeting. Public understanding of and involvement in the TMDL process was encouraged. Input from these meetings was utilized in the development of the TMDL and improved confidence in the allocation scenarios developed.

In addition to the open public meetings, MapTech, Inc. conducted a meeting on November 22, 1999 with twelve local farmers, identified and assembled by the Franklin County Farm Bureau. Through this meeting, insight into local farming practices that impact the delivery of fecal coliform to the streams was gained through conversation and a written survey of agricultural practices. The survey results formed much of the basis of the modeling efforts.

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1. INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act and USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (USEPA, 1991).

EPA's document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (USEPA, 1999) states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs .*
>
> *. . . A TMDL, or total maximum daily load, is a tool for implementing State water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

Gills Creek was initially listed as impaired on the 1996 *303(d) Total Maximum Daily Load Priority List and Report.* According to the *1998 303(d) Total Maximum Daily Load Priority List and Report* (VADEQ, 1998), Gills Creek is on the list for TMDL development and carries an agency watershed ID of VAW-L11R. Virginia Department of Environmental Quality has identified fecal coliform bacteria as the source of the impairment. The impaired stream segment has a length of 27.97 miles, beginning approximately 1.5 miles west of Route 684 bridge and extending to the confluence of Gills Creek with the Blackwater River in Smith Mountain Lake.

Gills Creek is part of the Blackwater River watershed, located in Franklin County, Virginia, just north of Burnt Chimney and approximately 15 miles to the south of Roanoke, Virginia (Figure 1.1). Gills Creek joins the Blackwater River watershed before emptying into Smith Mountain Lake, a reservoir on the Roanoke River. The Roanoke River flows southeast through a series of two additional reservoirs (John H. Kerr Reservoir and Gaston Lake), eventually emptying into the Albemarle Sound. The Gills Creek watershed is located within the Upper Roanoke hydrologic unit (USGS No. 03010101), and Virginia hydrologic planning unit L11. The land area of the Gills Creek watershed is approximately 27,417 acres, comprised of approximately 55% forest, 33% agricultural, 10% urban, with the balance being water bodies (Figure 1.2, Table 1.1). The estimated population within the Gills Creek drainage area in 2001 was 2,562. Franklin County ranks 2nd, among Virginia counties, for the number of dairy cows, 6th for the number of all cattle and calves, 19th for beef cattle, and 3rd for production of corn silage. (VASS, 1999). The Gills Creek watershed received average annual precipitation of approximately 47 inches, resulting in an average annual runoff volume of approximately 17 inches between 1977 and 1998.

Figure 1.1 Location of the Gills Creek watershed.

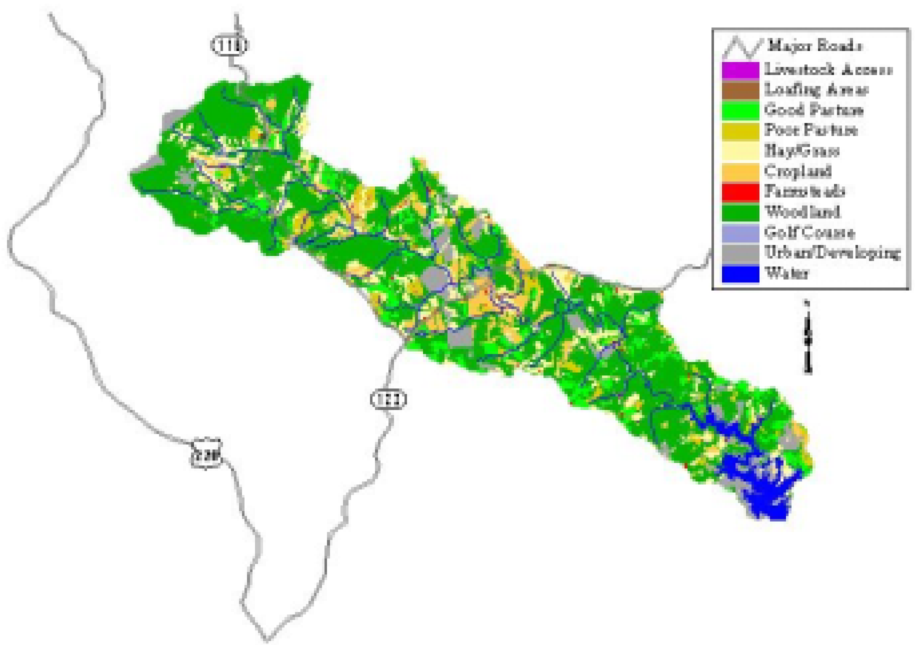

Figure 1.2 Land uses in the Gills Creek watershed.

Table 1.1 Gills Creek land use acreage.

Landuse	Acreage
Good Pasture	2,140
Poor Pasture	1,218
Cropland	1,870
Woodland	15,038
Urban/Developing	2,556
Farmsteads	110
Potential Livestock Access	207
Loafing Areas	24
Water	873
Golf Course	9
Hay/Grass	3,372

1.2 Applicable Water Quality Standards

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term "water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."

Virginia Water Quality Standards 9 VAC 25-260-10 (Designation of uses.) states:

A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.

♦

D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.

♦

G. The [State Water Quality Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentrations prevent the attainment of the use;

2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;

♦

6. Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standard for contact recreational use, VADEQ specifies the following criteria (Virginia Water Quality Standards 9 VAC 25-260-170):

A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.

If the waterbody exceeds either criterion more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (Virginia State Law 9VAC25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric criterion is applied.

Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported (VADEQ, 1998). Most of the VADEQ ambient water quality monitoring is done on a monthly or quarterly basis. This sampling frequency does not provide the two or more samples within 30 days needed for use of the geometric mean part of the standard. Therefore, VADEQ used the 1,000 cfu/100 ml standard in the 1996 and 1998 303(d) assessments of the fecal coliform bacteria monitoring data. A five-year time span was used for the assessment period.

For the Gills Creek watershed, the TMDL is required to meet the geometric mean criterion since the computer simulation gives 15-minute fecal coliform concentrations, analogous to 15-minute sample collection. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

1.3 Water Quality Standard Review

Two regulatory actions related to the fecal coliform water quality standard are currently under way in Virginia. The first rulemaking pertains to the indicator species used to measure bacteria pollution. The second rulemaking is an evaluation of the designated uses as part of the state’s triennial review of its water quality standards.

1.3.1 Indicator Species

USEPA has recommended that all States adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. USEPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and enterococci standard is scheduled for 2002 in Virginia.

1.3.2 Designated Uses

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard is described in 9 VAC 25-260-170 and in Section 1.2 of this report. This standard is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use.

In the TMDL public participation process, the residents in these watersheds often report that " people do not swim in this stream." It is obvious that many streams within the state are not used for recreational purposes. In many cases, insufficient depth of the streams as well as wildlife impacts prevent the attainment of the primary water quality standard.

Additionally, the VADEQ and VADCR have developed fecal coliform TMDLs for a number of impaired waters in the State. In some of the streams, fecal coliform bacteria counts contributed by wildlife result in standards violations, particularly during base flow conditions. Wildlife densities obtained from the Virginia Department of Game and Inland Fisheries and analysis or “typing” of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl contribute to the elevated fecal bacteria counts in these streams.

Recognizing that all waters in the Commonwealth are not used extensively for swimming, VA is considering re-designation of the swimming use for secondary contact in cases of: 1) natural contamination by wildlife, 2) small stream size, and 3) lack of accessibility to children. The widespread socio-economic impacts resulting from the cost of improving a stream to a “swimmable” status are also being considered.

The re-designation of the current swimming use in a stream will require the completion of a Use Attainability Analysis (UAA). An UAA is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and USEPA will have an opportunity to comment on these special studies.

1.3.3 Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all of the sources of fecal coliform (other than wildlife), the stream will not attain standards. TMDL allocation reductions of this magnitude are not realistic and do not meet USEPA’s guidance for reasonable assurance. Based on the water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. **Virginia and USEPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.** This is obviously an impractical action. While managing over-populations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL. In such a case, after demonstrating that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs, the state may decide to re-designate the stream’s use for secondary contact recreation or to adopt site specific criteria based on natural background levels of fecal coliforms. The state must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs through a so-called Use Attainability Analysis (UAA) as described above. All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and USEPA will be able to provide comment during this process.

Based on the above, USEPA and Virginia have developed a TMDL strategy to address the wildlife issue. The first step in this strategy is to develop an interim reduction goal as discussed in Chapter 6. The pollutant reductions for the interim goal are applied only to controllable, anthropogenic sources identified in the TMDL, setting aside any control strategies for wildlife. During the first implementation phase, all controllable sources would be reduced to the maximum extent practicable. Following completion of the first phase, VADEQ would re-assess water quality in the stream to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the second phase because the water quality standard exceedances attributed to wildlife in the model are very small and infrequent and fall within the margin of error.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Selection of a TMDL Endpoint and Critical Condition

USEPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Gills Creek is protected during times when it is most vulnerable.

Gills Creek was initially placed on the Virginia 1996 303(d) list of impaired waters based on monitoring performed between 1991 and 1995, and remained on the list for the 1998 assessment. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that this stream segment does not support the primary contact recreation use.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Gills Creek TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Section 1.2 of this document). In order to remove a water body from a state's list of impaired waters; the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of fecal coliform concentrations at 15-minute intervals, assessment of TMDLs was made using the geometric mean standard of 200 cfu/100 ml. Therefore, the in-stream fecal coliform target for this TMDL was a geometric mean not exceeding 200 cfu/100 ml.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Gills Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include nonpoint sources that are not precipitation driven (e.g. fecal deposition to stream).

A graphical analysis of fecal coliform concentrations and discharge showed that there was no obvious critical flow level (Figure 2.1). That is, the analysis showed no obvious dominance of either nonpoint sources or point sources. High concentrations were recorded in all flow regimes. Based on this analysis, a period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting period for hydrologic calibration was October 1994 through September 1998. For validation, the period selected was October 1980 through September 1981 and January 1991 through September 1994. TMDL development utilized a continuous simulation model that applies to both high and low flow conditions. Therefore, the critical conditions for Gills Creek were addressed during TMDL development.

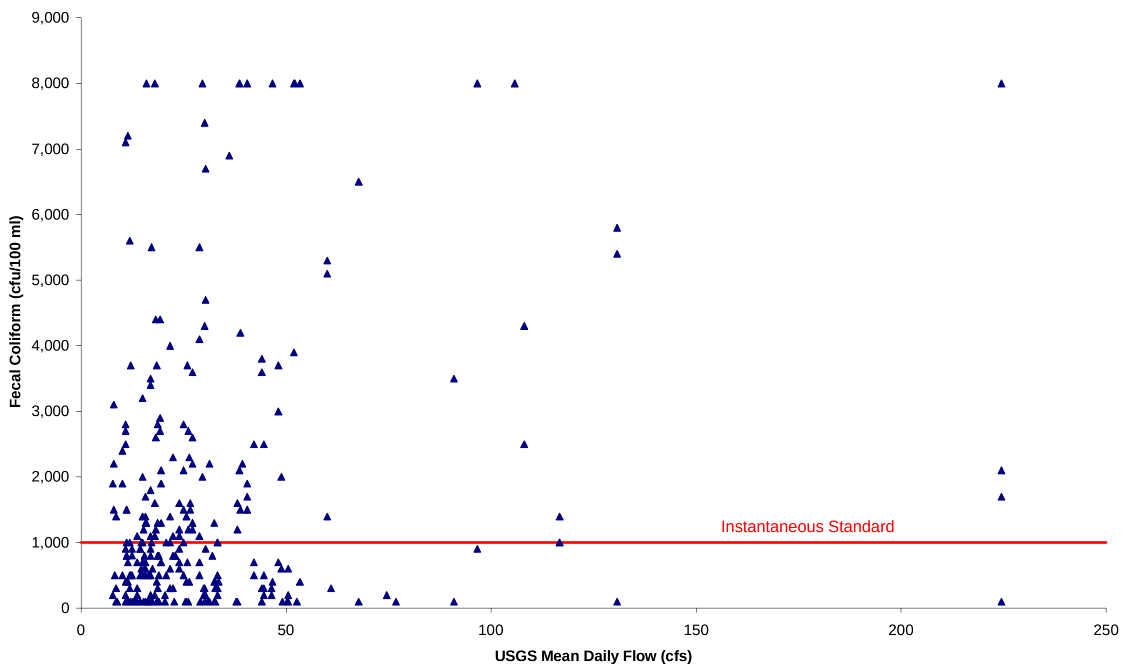

Figure 2.1 Relationship between fecal coliform concentrations from Gills Creek and discharge.

2.2 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Gills Creek watershed. Since water quality data are limited, an examination of all data available for the entire Gills Creek watershed was performed. Sources of data and pertinent results are discussed.

2.2.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information were:

- four VADEQ in-stream monitoring stations located in the Gills Creek; and
- water quality monitoring conducted by MapTech, Inc. as part of the services contracted for this TMDL.

2.2.1.1 Water Quality Monitoring Conducted by VADEQ

Data from in-stream fecal coliform samples, collected by VADEQ, for Gills Creek from July 1971 to August 2001 were included in the analysis. Samples were taken for the expressed purpose of determining compliance with the state standard limiting concentrations to less than 1,000 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of 8,000 cfu/100 ml were not further analyzed to determine the precise concentration of fecal coliform bacteria (i.e. censored). The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 cfu/100 ml most likely represent concentrations in excess of 8,000 cfu/100 ml. Table 2.1 summarizes the fecal coliform samples collected at the four VADEQ in-stream monitoring stations in the Gills Creek watershed. Monitoring site locations are shown in Figure 2.2.

Table 2.1 Summary of water quality sampling conducted by VADEQ.

Station Number	Count (#)	Minimum (cfu/100 ml)	Maximum (cfu/100 ml)	Mean (cfu/100 ml)	Median (cfu/100 ml)	Violations[1] (%)
4AGIL002.39	40	100	500	110	100	0
4AGIL004.46	31	100	800	148	100	0
4AGIL008.30	147	25	8,000	2,215	1,300	55
4AGIL023.22	152	100	8,000	1,242	700	35

[1]Violations are based on FC instantaneous standard (i.e. 1,000 cfu/100ml).

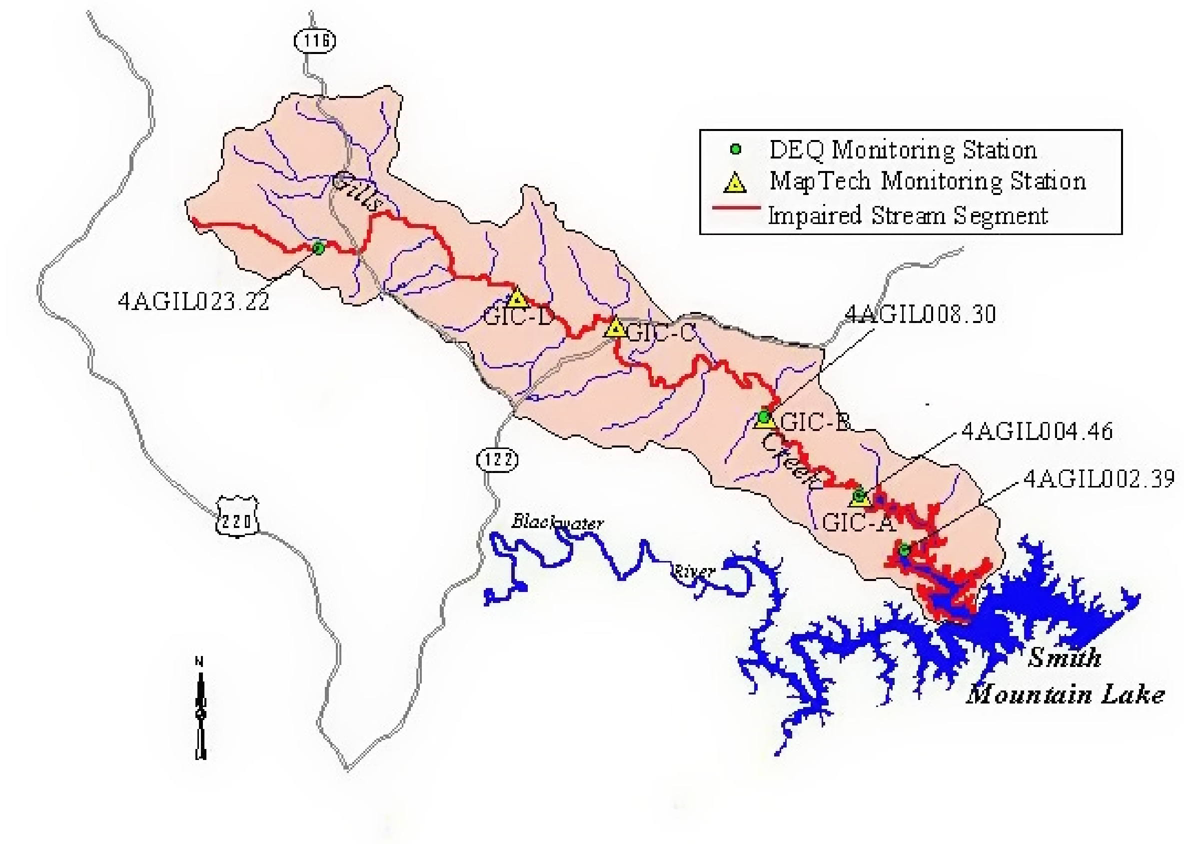

Figure 2.2 Location of water quality monitoring stations in the Gills Creek watershed.

2.2.1.2 Water Quality Monitoring Conducted by MapTech.

As a part of the services provided by MapTech to Virginia Department of Conservation and Recreation (VADCR), water quality samples were taken on four days (9/05/01, 10/01/01, 10/29/01, and 11/27/01) at four monitoring sites in the Gills Creek impairment during the contracted period. In addition, sampling was performed during a 12/11/01 storm event at all monitoring stations. All samples were analyzed for fecal coliform concentrations, *Enterococci*, and for bacterial source tracking by the Environmental

Diagnostics Laboratory at MapTech, Inc. Table 2.2 summarizes the fecal coliform concentration data collected by MapTech at MapTech monitoring stations during ambient conditions. Bacterial source tracking results of water samples collected at the stations are reported in Table 2.3. Fecal coliform and *Enterococci* concentrations and bacterial source tracking results of water samples collected during the storm event are listed in Table 2.4. Bacterial source tracking is discussed in greater detail in Section 2.2.2.2. All stations showed violations of the 1,000 cfu/100 ml instantaneous standard.

Table 2.2 Summary of water quality sampling conducted by MapTech. Fecal coliform concentrations (cfu/100 ml).

Station Number	Count (#)	Minimum (cfu/100 ml)	Maximum (cfu/100 ml)	Mean (cfu/100 ml)	Median (cfu/100 ml)	Violations[1] (%)
GIC-A	4	150	3,000	1,075	150	25
GIC-B	4	150	3,500	1,518	1,210	50
GIC-C	4	190	2,500	1,350	1,355	50
GIC-D	4	350	3,200	1,648	1,520	50

[1]Violations based on FC instantaneous standard (i.e. 1,000 cfu/100ml).

Table 2.3 Summary of bacterial source tracking results from water samples collected in the Gills Creek watershed during ambient conditions.

Station	Date	FC (cfu/100 ml)	Percent Isolates classified as: Human	Livestock	Wildlife
GIC-A	09/05/01	950	21	33	46
	10/01/01	3,000	21	67	12
	10/29/01	150	8	38	54
	11/27/01	200	0	54	46
GIC-B	09/05/01	2,000	4	38	58
	10/01/01	3,500	8	21	71
	10/29/01	150	0	46	54
	11/27/01	420	17	50	33
GIC-C	09/05/01	2,400	0	46	54
	10/01/01	2,500	4	50	46
	10/29/01	190	17	62	21
	11/27/01	310	8	67	25
GIC-D	09/05/01	2,500	12	42	46
	10/01/01	3,200	8	38	54
	10/29/01	350	13	54	33
	11/27/01	540	0	67	33

Table 2.4 Analysis results of water samples collected in Gills Creek during a 12/11/01 storm event.

Station	Fecal Coliform (cfu/100 ml)	*Enterococci* (cfu/100ml)	% Isolates Classified as Human	Livestock	Wildlife
GIC-A	25,000[a]	33,000	8.3	62.5	29.2
GIC-B	20,000[a]	25,000	8.3	58.4	33.3
GIC-C	18,000[a]	28,000	4.2	54.1	41.7
GIC-D	11,000[a]	20,000	12.5	79.2	8.3

[a] Violates the FC instantaneous standard (i.e. 1000 cfu/100ml).

2.2.1.3 Summary of In-stream Water Quality Monitoring Data

Because the data collected by MapTech were not censored at 8,000 cfu/100 ml, the maximum values provide insight into the potential concentrations of samples reported as 8,000 cfu/100 ml in the VADEQ data. In addition, the highest fecal coliform concentration measured was 25,000 cfu/100ml (Table 2.3). Collins et al. (1996) reported a peak value of 160,000 cfu/100 ml for fecal coliform concentrations in uncensored samples taken within the adjacent Maggodee Creek watershed, further indicating the potential for extreme values throughout the Gills Creek watershed. Additionally, the mean values reported throughout tend to be higher than the median values indicating the existence of extreme high values.

2.2.2 Analysis of Water Quality Monitoring Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.2.2.1 Summary of Frequency of Violations at the Monitoring Stations

All water quality data were collected at a time-step of at least one month. The state standard of 1,000 cfu/100 ml was used to test for violations. Of the samples collected in Gills Creek, 38% were in violation of the state standard. A distribution of fecal coliform concentrations at each sampling station in the watershed can be found in Appendix A.

2.2.2.2 Bacterial Source Tracking

MapTech, Inc. was contracted to do in-stream sampling and analysis of fecal coliform concentrations as well as bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (i.e. human, livestock, or wildlife) of fecal contamination in water bodies. While the short time-frame available, and the subsequent small number of observations taken in this case makes drawing conclusions difficult, the data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chance for success in implementing solutions.

Several procedures are currently under study for use in bacterial source tracking. The two being developed in Virginia that have shown promise include DNA fingerprinting and biochemical profiling using fecal streptococci. Both procedures are still very much experimental and no studies have yet been completed that compare the methods against each other. For this project, the biochemical profiling method was used to confirm the sources of fecal contamination in streams. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, livestock and wildlife sources in watersheds in Virginia. Compared to DNA fingerprinting, biochemical profiling is much quicker, typically analyzes many more isolates (e.g. 24 vs. 10 for DNA analysis), is generally less expensive, has survived limited court testing, and has undergone rigorous peer review from the scientific community. Additionally, observation of an increased number of isolates allows for an estimate of the relative proportions of the fecal indicator (e.g. *Enterococci*) originating from different sources. The results of sampling were reported as the percentage of isolates acquired from the sample that were identified as originating from human, livestock, or wildlife sources.

Figure 2.3 shows the relationship between fecal coliform concentration at the time of sampling and the percentage of isolates from each source. Each sample is represented by three symbols, one each representing the proportion of human isolates, livestock isolates and wildlife isolates within that sample. For example, the sample depicted directly to the left of the instantaneous standard on the graph indicates a fecal coliform concentration of 950 cfu/100ml with the predominate source of fecal contamination being wildlife (46%), followed by livestock (33%), and then human (21%), while the next sample to the left indicates a fecal coliform concentration of 540 cfu/100ml with the predominate source being livestock (67%), followed by wildlife (33%), and then human (0%). Due to the time constraints of the contract, an assessment of seasonal impacts could not be performed on these data.

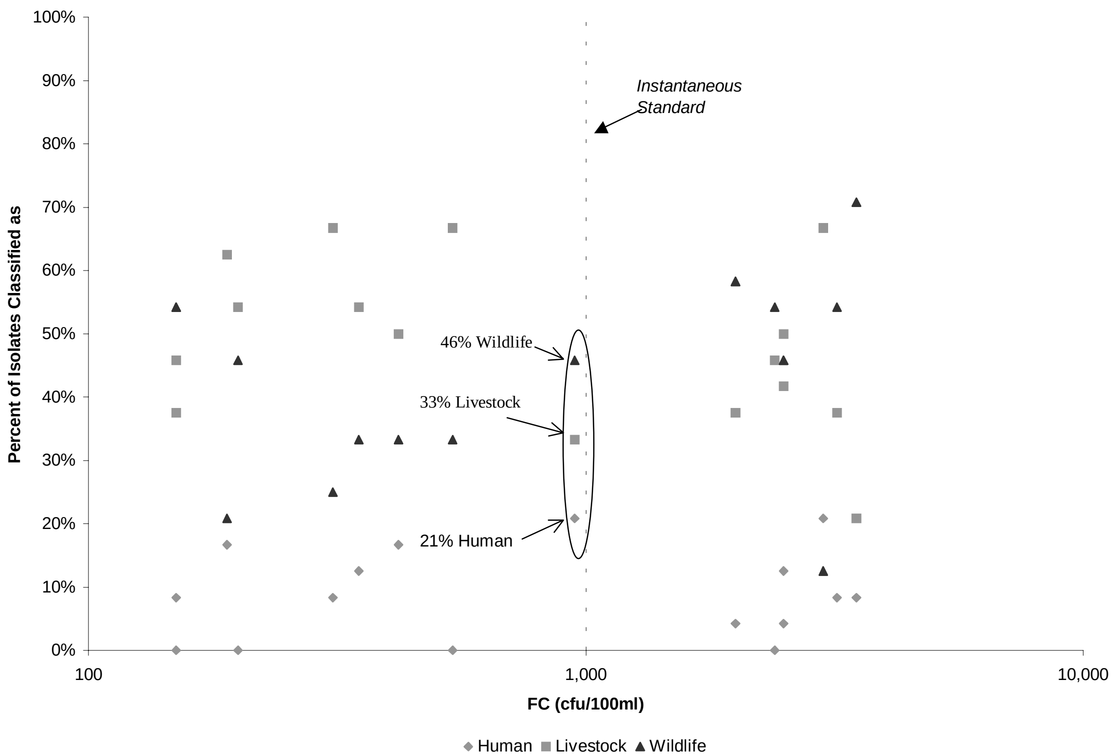

Figure 2.3 Results of MapTech's in-stream monitoring for fecal coliform concentrations and fecal sources.

2.2.2.3 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the

Seasonal Kendall Test can identify the trend (over many years) in bacteria levels during a particular season or month.

2.2.2.3.1 Precipitation

Total monthly precipitation measured at Rocky Mount, Virginia from October 1978 to September 1999, was analyzed, and no overall, long-term trend was found. However, for the month of January, a slight upward trend was detected from year to year. The slope of the increase in monthly precipitation for January was estimated at 0.16 in/year. The p-value calculated for this test was 0.08, indicating a high level of significance. No significant difference in monthly precipitation within years was detected.

2.2.2.3.2 Discharge

Mean monthly discharge measured at USGS Gaging Station #02056900 from October 1, 1978 to September 30, 1998, was analyzed, and an overall, long-term increase in discharge was observed. The slope of the increase in mean monthly discharge was estimated at 0.727 cfs/year. The p-value calculated for this test was 0.011, indicating a high level of significance. Much of this overall trend is likely due to an increasing trend for the months of January and February. The slope of the increase in mean monthly discharge for January and February was estimated at 3.69 and 4.21 cfs/year, respectively. The p-values calculated for both of these tests were 0.02, indicating a high level of significance. Differences in mean monthly discharge are indicated in Table 2.5. Discharges in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, January, May, June, November, and December are all in median group “C” and are not significantly different from each other. In general, discharges in the summer-fall months tend to be lower than discharges in the winter-spring months, with September and October tending to have the lowest flows and March having the highest.

Table 2.5 Summary of Moods Median Test on mean monthly discharge at USGS Station #02056900.

Month	Mean (cfs)	Minimum (cfs)	Maximum (cfs)	Median Groups[1]				
January	118.4	46.0	185.0			C		E
February	140.5	53.0	326.5				D	E
March	173.3	57.0	418.0					E
April	168.8	64.5	432.0				D	E
May	127.6	42.0	320.0			C	D	E
June	98.6	29.5	243.0		B	C	D	
July	66.1	20.0	156.0	A	B			
August	51.0	10.0	91.0	A	B			
September	56.9	18.0	151.0	A				
October	72.3	19.0	260.0	A				
November	84.7	27.5	204.5	A	B	C	D	
December	98.4	46.0	192.0		B	C	D	E

[1] Discharges in months with the same median group letter are not significantly different from each other at the 95% level of significance.

2.2.2.3.3 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in an earlier section (Section 2.2.1.1). Trend analysis was conducted on data collected at stations 4AGIL008.30 and 4AGIL023.22 in the Gills Creek drainage area. There was no overall trend in fecal coliform concentrations at these stations.

A seasonal analysis of fecal coliform concentration data was conducted using the Mood s Median Test. This test was used to compare median values of fecal coliform concentrations in each month. No significant differences between months within years were found. Table 2.6 summarizes the mean monthly fecal coliform concentrations at stations 4AGIL008.30 and 4AGIL023.22 in the Gills Creek drainage.

Table 2.6 Summary of mean monthly fecal coliform concentrations measured in the Gills Creek watershed.

Month	Mean (cfu/100ml)	Minimum (cfu/100ml)	Maximum (cfu/100ml)
January	175	15	200
February	439	63	2,200
March	613	25	1,200
April	2,067	63	5,000
May	1,790	100	8,000
June	1,874	138	3,175
July	2,306	100	2,856
August	1,418	100	8,000
September	1,005	175	1,789
October	700	200	1,200
November	1,580	100	6,900
December	506	113	900

3. SOURCE ASSESSMENT

The TMDL development described in this report included examination of all potential sources of fecal coliform in the Gills Creek watershed. The source assessment was used as the basis of model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This section documents the available information and interpretation for the analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Assessment of Point Sources

There is one point source permitted to discharge in the Gills Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Figure 3.1 shows the discharge location. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform concentrations, are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the 200 cfu/100 ml limit.

Windy Gap Elementary School Waste Water Treatment Plant is the only permitted point discharge in the Gills Creek drainage area (Figure 3.1). According to the current VPDES permit (#VA0090719), Windy Gap Elementary School WWTP has a design discharge of 0.004 MGD, and is required to maintain a fecal coliform geometric mean concentration of 200 cfu/100ml.

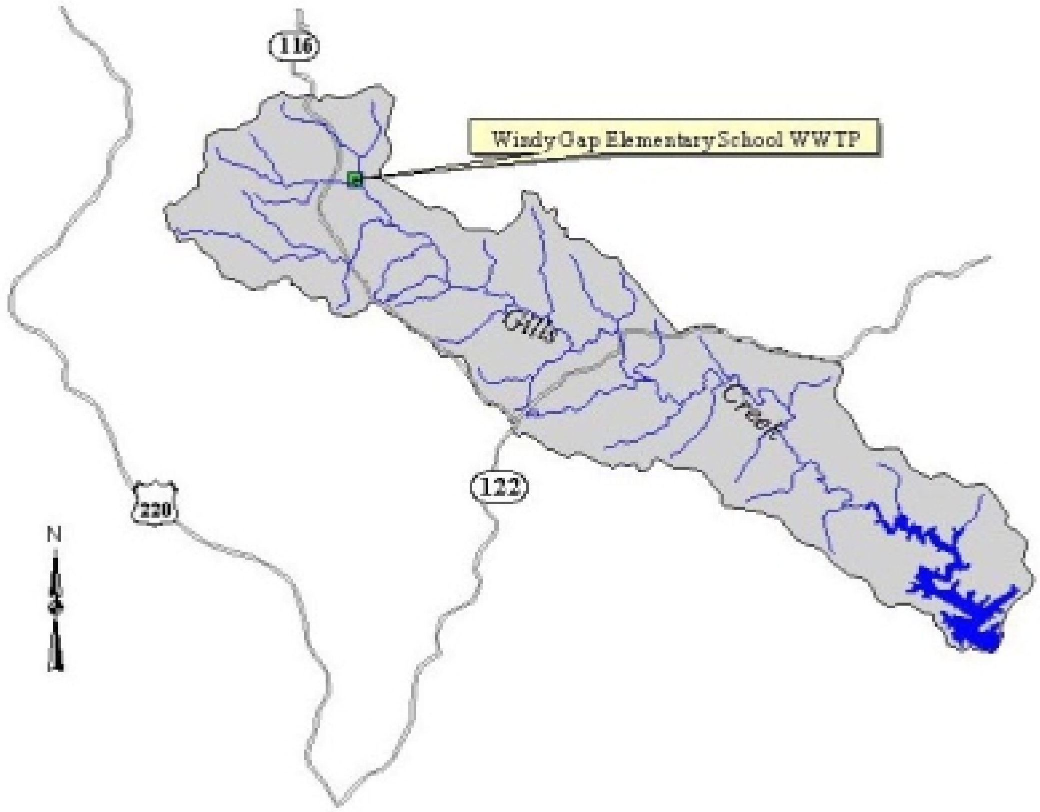

Figure 3.1 Location of VPDES permitted point source in the Gills Creek watershed.

3.2 Assessment of Nonpoint Sources

In the Gills Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources included private residential sewage treatment systems, land application of waste (livestock and biosolids), livestock, wildlife, and pets. MapTech collected samples of fecal coliform sources (i.e. wildlife, livestock, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process and expand the database of known fecal coliform sources for purposes of bacterial source tracking (Section 2.2.2.2). Where appropriate, spatial distribution of sources was also determined.

3.2.1 Private Residential Sewage Treatment

According to 1990 Census data for Franklin County, there were 14,267 septic systems in operation in the county (FCBS, 1995). Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field.

Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems from a stream contribute virtually no fecal coliform to surface waters. Reneau (2000) reported that a very small portion of fecal coliform can survive in the soil system for over 50 days. This number might be higher or lower depending on soil moisture and temperature. An analysis of soil system hydrology for soils typical of the area revealed that lateral movement of 50 feet in 50 days would not be unusual. Weiskel et al. (1996) reported less than 0.01% delivery of fecal coliform from sub-standard septic systems (i.e. drain field extending below water table) to a point 6.5 feet down gradient from the system. Based on these analyses, it was estimated that properly functioning septic systems within 50 feet of a stream contribute, on average, 0.001% of fecal coliform production.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in stream due to proximity. A permit from the Virginia Department of Health (VDH) is required for installing or repairing a septic system. During development of the TMDLs for the upper four Blackwater River impairments, VDH reported 186 permits issued in the first 9 months of 1999 for repairs to septic systems. Based on this report, 248 total permits were projected for 1999. Baker (2000) reported that this number could be increased by 0.5% to account for unreported failures. In September 2000, VDH reported the total number of permits issued for repair of septic systems in 1999, in Franklin County, was 54, which was less than the original estimate for the first 9 months of 1999. Based on a survey of the major septic pump-out contractors in Franklin County, the average annual number of septic failures, where the failure was evident on the landscape, was 232. The survey also showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard. The percentage of failures based on the total number of septic systems in Franklin County and the number of failures in the original VDH report, the revised VDH report, and the survey of pump-out contractors, was 1.3%, 0.3%, and 1.2%, respectively. Septic system failure rates used in TMDL development in rural areas of Virginia range from 2.5 %, reported by VADEQ (1999), to failure rates based on system age of 40% failure in the oldest homes and 5% failure in the newest (VADEQ, 2000). While it is clear that failure rates based on permit numbers and surveys of pump-out contractors do not take into account septic failures that go unreported and un-repaired, there was no evidence available to support the failure rates used in similar TMDL development across the state. The resulting septic system failure rate utilized was 1.2%.

The 1990 Census (USCB, 1990) reported three categories of sewage treatment; public sewage treatment systems, private sewage treatment systems, and "other." "Other" included portable toilets, latrines, and direct discharge of waste. The “other” category accounted for approximately 4% of the households in Franklin County. Additionally, the *1995 Comprehensive Plan* for Franklin County (FCBS, 1995) reported that approximately 2.5% of households lack complete plumbing (i.e. hot and cold water, flush toilet, and bathtub/shower). Baker (1999) reported that 0.5% of the number of private sewage systems was a good estimate for the number of households directly depositing sewage to streams.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml. An average fecal coliform density for human waste of 642,000 cfu/g was measured in samples collected by MapTech. Geldreich (1978) reported a total waste load of 75 gal/day/person.

3.2.2 Livestock

The predominant types of livestock in the Gills Creek watershed are dairy and beef cattle, although all types of livestock identified were considered in modeling the watershed. Animal populations were based on a 1998 livestock inventory performed in the *Blackwater River Riparian NPS Pollution Control Project* (MapTech, 1999) by Ferrum College, watershed visits, and verbal communication with farmers. In the inventory, each farm was assigned a livestock site map index code, which was equivalent to either the United States Department of Agriculture/Farm Services Agency (USDA/FSA) farm or tract number with the breakdown of animals associated with that farm. The inventory was updated to 2001 conditions by accounting for such things as farms going out of business, herd size differences, animal type changes, and new farms and animals. Table 3.1 depicts a partial listing of information contained in the livestock inventory. The inventory also included information regarding the management of livestock (e.g. time in loafing lot, percentage of waste collected, etc.).

Table 3.2 gives a summary of livestock populations in the Gills Creek watershed. Values of fecal coliform density of livestock sources were based on sampling done in the watershed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.3.

Table 3.1 Partial listing of information contained in livestock inventory of Blackwater Riparian NPS Pollution Control Project.

Livestock Site Map Index Code	Number of Animals	Average Weight (lb)	Time in Loafing Lot (hrs)	Waste Collected (%)	Stream Access (hrs)	Collected Waste Spread (%)	Time on Farm (months)	Loafing Area (ac)	Animal Type
1	75	1,350	24	75	0	100	12	8	dairy
2	76	1,350	24	50	12	100	12	6	dairy
3	78	1,350	24	33	0	100	12	12	dairy
*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*
216	7	1,050	0	0	1.2	0	12	0	beef
217	6	250	0	0	1.2	0	9	0	beef
218	100	1,350	0	0	1.2	0	12	0	dairy
219	100	500	0	0	1.2	0	12	0	dairy

Table 3.2 Livestock populations in the Gills Creek watershed.

Animal Type	Number of Animals
Dairy	
Milk Cows	519
Dry Cows	260
Replacement Heifers	259
Beef	1,453
Horse	38
Goat	8

Table 3.3 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	FC Density (FC/g)
Dairy (1,400 lb)	120.4	258,000
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Donkey	51.0	99,000 [1]
Sheep (60 lb)	2.4	43,000
Goat (140 lb)	5.7	15,500
Dairy Separator	N/A	32,000
Dairy Storage Pit	N/A	1,200 [2]

[1] Fecal coliform density for donkey feces was assumed to be equal to that of horse.
[2] Units are CFU/100ml.

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (e.g. pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Dairy production is the primary source of land-applied livestock waste in the Gills Creek watershed. No beef producer was identified as collecting and applying a portion of the beef cattle waste to cropland that was produced on the farm. However, all land-applied livestock waste was treated as dairy cattle waste in terms of the amount of fecal coliform bacteria expected. Time in confinement was taken from data reported in the *Blackwater River Riparian NPS Pollution Control Project* (Table 3.1). Average values of time spent in confinement taken from a farmer survey conducted by MapTech on 11-22-99 were used where numbers were not available for individual farms (Table 3.4). This survey also provided estimates of the timing of applications throughout the year (Table 3.5).

Table 3.4 Average time milking cows spend in different areas per day. Based on farmer survey, 11/22/99.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot - Confinement (hr)
January	7.2	0.5	16.3
February	7.2	0.5	16.3
March	7.6	1.0	15.4
April	8.6	1.5	13.9
May	9.3	1.5	13.2
June	9.3	2.0	12.7
July	9.8	2.0	12.2
August	9.8	2.0	12.2
September	10.3	1.5	12.2
October	10.5	1.0	12.5
November	9.8	1.0	13.2
December	8.9	0.5	14.6

Table 3.5 Average percentage of collected waste applied throughout year.

Month	Applied as % of Total	Land Use
January	1.50	Cropland
February	1.75	Cropland
March	17.00	Cropland
April	17.00	Cropland
May	17.00	Cropland
June	1.75	Pasture
July	1.75	Pasture
August	1.75	Pasture
September	5.00	Cropland
October	17.00	Cropland
November	17.00	Cropland
December	1.50	Cropland

All livestock were expected to deposit some portion of waste on land areas. The average time per day spent on pasture for dairy and beef cattle was reported by the *Blackwater River Riparian NPS Pollution Control Project* (Table 3.1). Average values of time spent in confinement taken from a farmer survey conducted on 11-22-99 were used where numbers were not available for individual farms. The average time per day spent in pasture by dairy cattle is reported in Table 3.4. The percentage of time spent in pasture by beef cattle is reported in Table 3.6. Horses, sheep, donkeys, and goats were assumed to be in pasture 100% of the time.

Only dairy and beef cattle were expected to make a significant contribution through direct deposition to streams. The average amount of time spent by dairy and beef cattle in stream access areas (i.e. within 66 feet of the stream) to streams for each month is given in Table 3.4, Table 3.6 and Table 3.7.

Table 3.6 Average time beef cows spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.0	1.0	0
February	23.0	1.0	0
March	22.5	1.5	0
April	22.0	2.0	0
May	22.0	2.0	0
June	21.5	2.5	0
July	21.5	2.5	0
August	21.5	2.5	0
September	22.0	2.0	0
October	22.5	1.5	0
November	22.5	1.5	0
December	23.0	1.0	0

Table 3.7 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.5	0.5	0
February	23.5	0.5	0
March	23	1	0
April	22.6	1.4	0
May	22.6	1.4	0
June	22.1	1.9	0
July	22.1	1.9	0
August	22.1	1.9	0
September	22.6	1.4	0
October	23	1	0
November	23	1	0
December	23.5	0.5	0

3.2.3 Biosolids

Biosolids produced at the Roanoke Wastewater Treatment Plant (RRWWTP) and the Upper Smith River Wastewater Treatment Plant (USRWWTP) are applied to agricultural lands in Franklin County. In 1998, 454 dry tons of RRWWTP biosolids, containing approximately 4.16×10^{10} cfu of fecal coliform were applied in the Gills Creek drainage area. Also, in 1998, 474 dry tons of USRWWTP biosolids, containing approximately 2.95×10^{13} cfu of fecal coliform were applied in the Gills Creek drainage area. In 2000, 2,722 dry tons of RRWWTP biosolids, containing approximately 2.50×10^{11} cfu of fecal coliform, were applied in the Gills Creek drainage area. The application of biosolids to agricultural lands is strictly regulated in Virginia (VDH, 1997). Biosolids are required to be spread according to sound agronomic requirements and consideration for topography and hydrology. Class B biosolids may not have a fecal coliform density greater than 1,995,262 cfu/g (total solids). Application rates must be limited to a maximum of 15 dry tons/ac per three-year period. Average fecal coliform densities measured were 101 cfu/g and 68,467 cfu/g for RWWTP and USRWWTP, respectively (MapTech, 1999).

3.2.4 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), citizens from the watershed, faculty at Ferrum College, source sampling, and site visits. Population densities were provided by VDGIF and are listed in Table 3.7 (Farrar, 2002; Knox, 2002; Norman and Lafon, 1998; and Rose and Cranford, 1987). The numbers of animals estimated to be in the Gills Creek watershed are reported in Table 3.8. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2000; Norman, 1999; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Costanzo, 2000; Weiskel et al., 1998, and Yagow, 1999). Table 3.9 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife waste done in the watershed by MapTech. The only value that was not obtained from sampling in the watershed was for beaver. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas are reported in Table 3.10.

Table 3.7 Wildlife population density.

Animal	Density	Density Unit
Raccoon	0.070	an/ac of habitat
Muskrat	2.751	an/ac of habitat
Beaver	4.800	an/mi of stream
Deer	0.047	an/ac of habitat
Turkey	0.010	an/ac of forest
Goose	0.004	an/ac
Mallard	0.002	an/ac

Table 3.8 Wildlife populations in the Gills Creek watershed.

Species	Number of Animals
Raccoon	336
Muskrat	902
Beaver	51
Deer	1,489
Turkey	295
Goose	110
Mallard	55

Table 3.9 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of stream and ponds Less frequent = region between 601 and 7,920 ft
Muskrat	100	Continuous stream below 1,300 ft elevation; Primary = region within 66 ft of stream and ponds Less frequent = region between 67 and 300 ft
Beaver[1]	200	Continuous stream below 1,300 ft elevation; Primary = region within 300 ft of stream and ponds Less frequent = region between 301 and 656 ft
Deer	772	All area of the watershed
Turkey[2]	320	All area of watershed excluding farmsteads and urban land uses
Goose[3]	225	Continuous stream below 1,300 ft elevation; Primary = region within 66 ft of stream and ponds Less frequent = region between 67 and 300 ft
Mallard	150	Continuous stream below 1,300 ft elevation; Primary = region within 66 ft of stream and ponds Less frequent = region between 67 and 300 ft

1 Beaver waste load was calculated as twice that of muskrat, based on field observations.
2 Waste load for domestic turkey (ASAE, 1998).
3 Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2000).

Table 3.10 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

3.2.5 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the watershed and were the only pets considered in this analysis. Cat and dog populations were derived from Lehigh Valley Animal Rights Coalition for United States averages in 1996. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout by MapTech. A summary of the data collected is given in Table 3.11.

Table 3.11 Pet population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Total Population (an)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	1.7	2,246	450	480,000
Cat	2.2	2,906	19.4	726

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Gills Creek watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

The stream segment within each subwatershed is simulated as a single reach of open channel, referred to as a RCHRES. Water and pollutants from pervious and impervious land segments (i.e. PERLNDs and IMPLNDs) are transported to the RCHRES using mass links. Mass links are also used to connect the modeled RCHRES segments in the same configuration the real stream segments are found in the physical world. The same mass link principal is applied when water and pollutants are conveyed to a RCHRES via a point discharge, or water is withdrawn from a particular RCHRES. On a larger scale, impaired stream segments are also linked to one another by mass links. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

To adequately represent the spatial variation in the watershed, the Gills Creek drainage area was divided into nine subwatersheds (Figure 4.1). The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model. Water quality data (i.e. fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1). The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. Given this modeling constraint and the desire to maintain a spatial distribution of watershed characteristics and associated parameters, a 15-minute modeling time-step was determined to be required. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

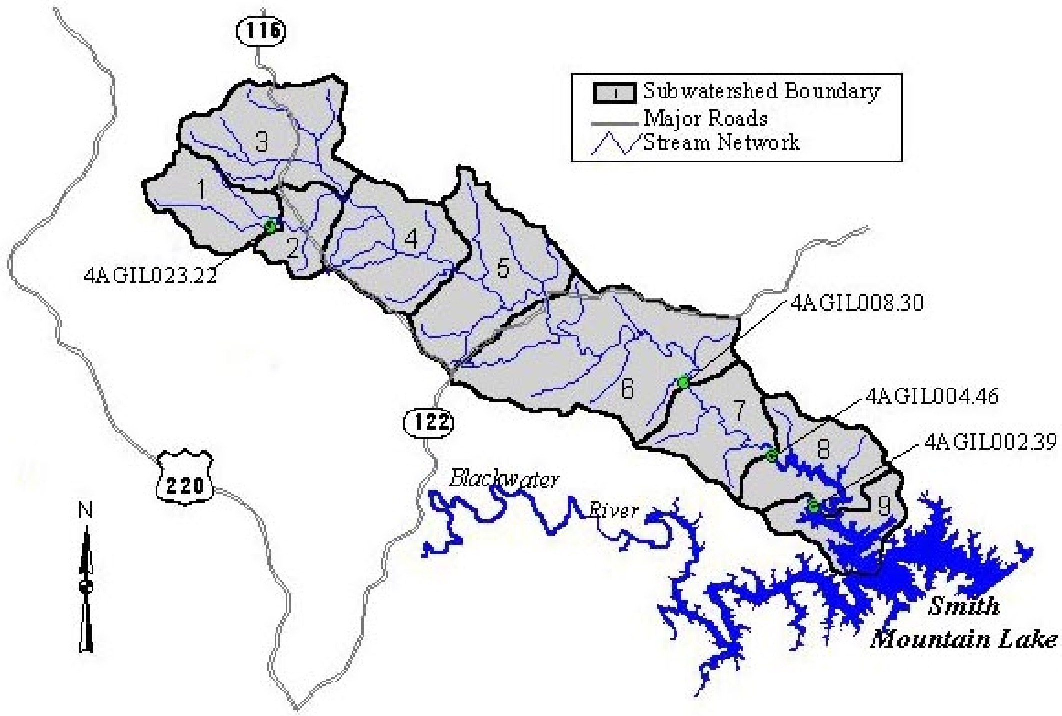

Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations in the Gills Creek watershed.

Within each subwatershed, up to eleven land use types were represented. Each land use had parameters associated with it that described the hydrology of the area (e.g. average slope length) and the behavior of pollutants (e.g. fecal coliform accumulation rate). Table 4.1 shows the different land use types and the associated area of each. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). All of the impervious areas in the watershed are represented in one IMPLND type, while there are ten PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (e.g. slope length) vary with the particular subwatershed in which they are located. Others vary with season (e.g. upper zone storage) to account for management and biological changes.

Table 4.1 Gills Creek land use acreage.

Land Use	Acreage
Good Pasture	2,140
Poor Pasture	1,218
Cropland	1,870
Woodland	15,038
Urban/Developing	2,556
Farmsteads	110
Livestock Access to Streams	207
Loafing Area	24
Water	873
Golf Course	9
Hay/Grass	3,372

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter, (mechanically applied and deposited directly) die-off was addressed implicitly through monitoring and modeling. Samples of collected waste (i.e. dairy waste from loafing areas) were locally collected and analyzed prior to land application. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with land use type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (e.g. animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by the first-order exponential equation, described above.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (e.g. population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 1994 were used for the water quality calibration and validation period (1991-1995). Data representing 2001 were used for the allocation runs in order to represent current conditions. Additionally, data projected to 2006 were analyzed to assess the impact of changing populations.

4.3.1 Point Sources

Windy Gap Elementary School WWTP is the only permitted point discharge in the Gills Creek drainage area scheduled to start discharging in 2004. During allocation runs, the design flow capacity (0.004 MGD) was used. This flow rate was combined with a fecal coliform concentration of 200 cfu/100ml to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels.

Nonpoint sources of pollution that were not driven by runoff (e.g. direct deposition of fecal matter to the stream by wildlife) were modeled similarly to point sources. These sources as well as land-based sources are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

The number of septic systems in the nine subwatersheds modeled for the Gills Creek watershed were calculated by overlaying 1990 Census group-block and block data (USCB, 1990) with the watershed to enumerate households. Data from the 1990 Census was used due to the unavailability of detailed 2000 Census spatial data. These numbers were projected to 1994, 2001, and 2006 using the growth rate for Franklin County reported in the 2000 Census (USCB, 2000). Households were then distributed among farmstead and urban land-use types. The total number of households, reported by the 1990 Census, included farmsteads, which were assumed to have septic systems. Ferrum College (MapTech, 2001) reported the number and location of farmsteads in the watershed. Each farmstead land-use area was assigned a number of septic systems based on this data. Of the remaining households, only a percentage was reported to be on private sewage (septic) systems (FCBS, 1995). These households were assigned to the urban land-use type. A total of 1,165 septic systems was estimated in the Gills Creek watershed in 1994. During allocation runs, the number of households was projected to 2001, based on current, Franklin County growth rates (USCB, 2000) resulting in 1,314 septic systems (Table 4.2). The number of septic systems was projected to increase to 1,420 by 2006.

Table 4.2 Estimated failing septic systems.

Watershed	Total Septic Systems	Failing Septic Systems	Straight Pipes
Gills	1,314	17	7

4.3.2.1 Functional Septic Systems

Using a procedure developed by MapTech, 1990 Census data (USCB, 1990), overlaid with urban land use and hydrography maps of the watershed, were analyzed to determine the percentage of households with septic systems that were located within 50 feet of a stream. This number was then projected to 1994, 2001, and 2006. The resulting numbers of septic systems within 50 feet of a stream were 89, 99, and 109, respectively. It was estimated for these homes that 0.001% of the fecal coliform produced in the household would reach the stream through lateral flow. The average number of people per household in each of the nine subwatersheds was used to determine the waste load from each house, and the values reported in Section 3.2.1 for human waste load and fecal coliform density were used to determine the fecal coliform load.

4.3.2.2 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. A septic system failure rate of 1.3% was used in development of the TMDLs for the six impairments of the Blackwater watershed, based on the number of septic-repair permits reported by VDH for the first 9 months of 1999. The failure rate calculated based on a survey of septic pump-out contractors was 1.2% and in agreement with the estimate based on permits. VDH subsequently reported permit levels that would indicate a 0.3% failure rate for 1999. VDH also reported that an additional 0.5% of failures might go unreported. In order to be consistent with modeling performed for the Blackwater River impairments, because it is in general agreement with the survey of septic pump-out contractors, and because it takes into account some un-repaired septic failures, the septic system failure rate of 1.3% was used in modeling this impairment. The survey of septic pump-out contractors also indicated that the majority of failures occurred at homes that were over 20 years old. The total number of failing septic systems in the watershed was therefore distributed among subwatersheds based on the number of homes over 20 years old. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on the survey of septic pump-out contractors to account for more frequent failures during wet months.

4.3.2.3 Uncontrolled Discharges

The number of uncontrolled discharges was estimated to be equal to 0.5% of the number of septic systems in the Gills Creek watershed (Section 3.2.1). Since older homes are more likely to have uncontrolled discharges, the number of uncontrolled discharges was distributed among subwatersheds based on the number of homes in each subwatershed that were built more than 30-years prior. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways; land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2001 were used for the allocation runs, while these numbers were projected back to 1994 for the calibration and validation runs, based on Franklin County growth rates determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995; VASS 2001). Similarly, when growth was analyzed, livestock numbers were projected to 2006. For land-applied waste, the fecal coliform density measured from waste storage pit effluent during land application was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.3). The use of fecal coliform densities measured in pit-stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.3.3.1 Land Application of Collected Manure

The only significant collection of livestock manure occurs on dairy farms. For each dairy farm in the drainage area, the average daily waste production per month was calculated using the number of cows, weight of animal, and waste production rate as reported in Section 3.2.2. The amount of waste collected was first based on proportion of milking cows, as the milking herd represented the only cows subject to confinement and therefore waste collection. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. If beef cattle were reported as being confined for some percentage of time, the waste produced while in confinement was added to this total. Finally, values for the percentage of loafing lot waste collected, taken from the livestock inventory conducted by Ferrum College and reported by MapTech (2001), were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.1). Average percentage of waste applied throughout the year for each land use reported in the farmer survey was used to distribute land-applied waste. It was assumed that 100% of land-applied waste is available for transport in surface runoff transport unless the waste is incorporated in the soil by plowing during seedbed preparation. Percentage of cropland plowed and amount of waste incorporated was adjusted using calibration for the months of planting.

4.3.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the livestock inventory conducted by Ferrum College and reported by MapTech (2001). Where data availability was lacking, average values based on the farmer survey conducted on 11-22-99 were used. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse, sheep, donkey, and goat) were assumed to deposit all feces on pasture. Pasture land-use types were divided into good and poor pasture. The total amount of fecal matter deposited on each of these land-use types was area-weighted on a farm-by-farm basis.

4.3.3.3 Direct Deposition to Streams

Dairy and beef cattle are the primary sources of direct deposition by livestock in the Gills Creek watershed. The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the livestock inventory conducted by Ferrum College and reported by MapTech (1999). Where data availability was lacking, average values based on the farmer survey conducted on 11-22-99 were used. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" land use, 70% of the waste was modeled as being directly deposited in the stream and 30% remained on the land segment adjacent to the stream. The 30% remaining was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 70% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

In 1998, 454 dry tons of RRWWTP biosolids, containing approximately 4.16×10^{10} cfu of fecal coliform were applied in the Gills Creek drainage area (VDH, 2001). Also, in 1998, 474 dry tons of USRWWTP biosolids, containing approximately 2.95×10^{13} cfu of fecal coliform were applied in the Gills Creek drainage area (VDH, 2001). In 2000, 2,722 dry tons of RRWWTP biosolids, containing approximately 2.50×10^{11} cfu of fecal coliform, were applied in the Gills Creek drainage area (VDH, 2001). This application was accounted for during water quality calibration of the model. With urban populations growing, the disposal of biosolids will take on increasing importance. Class B biosolids have been measured with 68,467 cfu/g-dry and are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. During modeling of current conditions, no biosolids applications were modeled, however, the sensitivity analysis provided insight into the effects that increased applications of biosolids could have on water quality.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.4). An example of one of these layers is shown in Figure 4.2. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

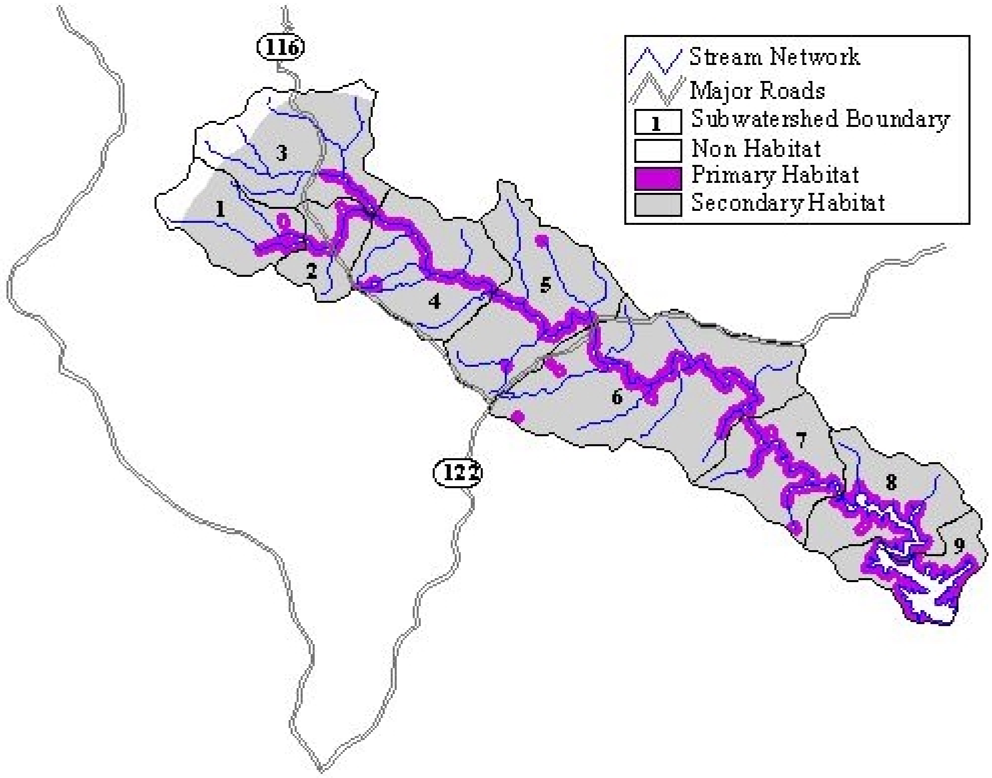

Figure 4.2 Example of habitat layer developed by MapTech (raccoon habitat in the Gills Creek watershed).

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns. No seasonal variation was assumed for the remaining species. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.10). It was estimated that for all animals other than beaver that 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. To account for unquantifiable fecal coliform loads from known wildlife species, a background load was applied to all land segments at 10% of the total land-based wildlife load, and the total direct-deposition wildlife load was increased by 10%. No long-term (1994 – 2006) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in Section 3.2.5. Waste from pets was distributed in the urban and farmstead land uses. The location of households was taken from the 1990 Census (USCB, 1990). The land use and household layers were overlaid which resulted in number of households per land use. The number of animals per land use was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load from pets was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1994, 2001, and 2006 based on human population growth rates.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (e.g. stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at the subwatershed outlets. One outlet was considered the beginning of the next reach, when appropriate. In the case of a confluence, sections were surveyed above the confluence for each tributary and below the confluence on the main stream.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed and consisted of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

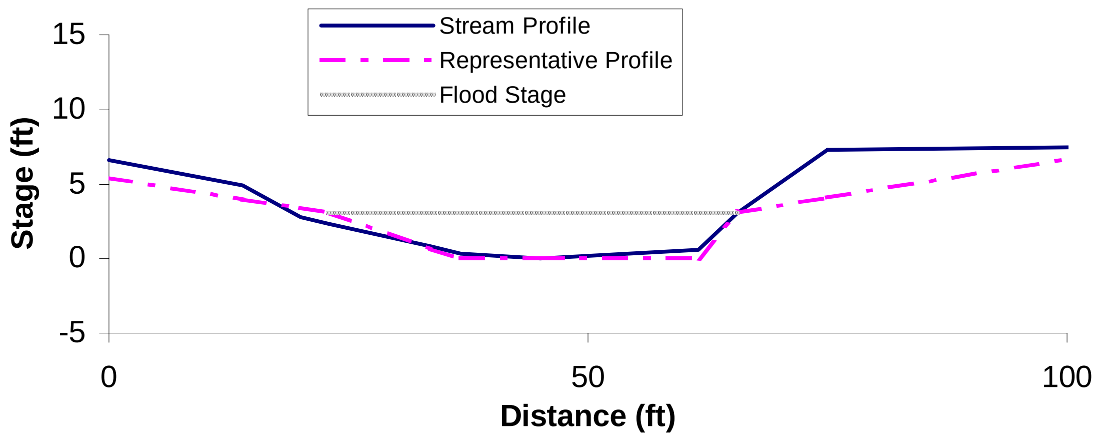

Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (i.e. Manning's *n*) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, *n*. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's *n*. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters was collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's *n* for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.3). The F-tables developed consist of four columns; depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. A maximum depth of 50 ft and 120 ft were used in the F-tables for the seven upper reaches and the two lower reaches, respectively. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

Table 4.3 Example of an "F-table" calculated for the HSPF Model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0.0	21.75	0.00	0.00
0.2	21.96	4.37	10.87
0.4	22.16	8.78	34.54
0.6	22.36	13.23	67.92
0.8	22.56	17.73	109.75
1.0	22.77	22.26	159.29
1.3	23.07	29.14	246.88
1.7	23.48	38.44	386.59
2.0	23.78	45.53	507.43
2.3	24.08	52.71	641.30
2.7	24.49	62.43	839.20
3.0	24.79	69.82	1,001.68
6.0	29.42	149.62	3,222.35
9.0	37.08	249.37	6,254.60
12.0	44.73	372.08	10,078.05
15.0	52.38	517.75	14,818.37
25.0	77.32	1,163.48	38,629.43
50.0	92.02	2,796.19	103,246.75

4.5 Selection of Representative Modeling Period

Selection of the modeling period was based on two factors; availability of data (discharge and water quality) and the need to represent critical hydrological conditions. Mean daily discharge data at USGS Gaging Station #02056900 were available from October 1976 to September 1998. Mean 30-minute discharge data (based on 15-minute instantaneous measurements) was available from October 1994 to June 1999. The most comprehensive period for reported fecal coliform concentrations was during the assessment period from May 1991 to September 1995. The fecal coliform concentration data were evaluated for use during calibration and validation of the model. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration. During validation, no adjustments are made to model parameters. The goal of validation is to assess the capability of the model in hydrologic conditions other than those used during calibration.

As reported in Section 2.1, high concentrations of fecal coliform were recorded in all flow regimes, and a period for calibration and validation was chosen based on the overall distribution of wet and dry seasons. The mean daily flow and precipitation for each season were calculated for the period October 1977 through September 1998. This resulted in 21 observations of flow and precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The initial period was chosen based on the availability of mean 30-minute discharge data (10/1/94 – 9/30/98). Additional years, beginning with the fecal coliform assessment period (5/91 – 9/95), were added until the mean and variance of each season in the modeled period was not significantly different from the historical data (Table 4.4). Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for hydrologic calibration was October 1994 thru September 1998. For hydrologic validation, the period selected was October 1980 through September 1981 and January 1991 through September 1994.

Table 4.4 Comparison of modeled period to historical records.

	Mean Flow (cfs)				Precipitation (in/day)			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1978 - 1998)							
Mean	101	155	211	99	0.1223	0.1151	0.1365	0.1422
Variance	4,948	2,621	12,214	1,964	0.0023	0.0017	0.0018	0.0027
	Calibration & Validation Period (10/80 - 9/81, 1/91 - 9/98)							
Mean	77	172	194	101	0.1082	0.1285	0.1341	0.1375
Variance	3,320	3,749	7,442	2,611	0.0023	0.0016	0.0015	0.0032
	P-Values							
Mean	0.178	0.228	0.322	0.453	0.241	0.203	0.440	0.416
Variance	0.289	0.762	0.224	0.719	0.536	0.495	0.396	0.648

4.6 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Qualities of fecal coliform sources were modeled as described in Chapters 3 and 4. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable. The modeled design included the entire Gills Creek watershed. Model simulations were run for both impairments simultaneously.

4.6.1 Hydrologic Calibration and Validation

Parameters that were available for adjustment during the hydrologic calibration represented the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (LSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), and the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), forest coverage (FOREST), slope of overland flow plane (LSUR), groundwater recession flow (KVARY), maximum and minimum air temperature affecting PET (PETMAX, PETMIN, respectively), infiltration equation exponent (INFEXP), infiltration capacity ratio (INFILD), active groundwater storage PET (AGWETP), Manning's *n* for overland flow plane (NSUR), interception (RETSC), weighting factor for hydraulic routing (KS). Table 4.5 contains the typical range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

Table 4.5 Model parameters utilized for hydrologic calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	----	0.0 – 0.95	0.0	0.0
LZSN	in	2.0 – 15.0	14.2	15.0
INFILT	in/hr	0.001 – 0.50	0.056 – 0.250	0.059 – 0.262
LSUR	ft	100 – 700	15 – 1260	15 –1260
SLSUR	----	0.001 – 0.30	0.0001 – 0.173	0.0001 – 0.173
KVARY	1/in	0.0 – 5.0	0.0	0.0
AGWRC	1/day	0.85 – 0.999	0.98	0.98
PETMAX	deg F	32.0 – 48.0	40.0	40.0
PETMIN	deg F	30.0 – 40.0	35.0	35.0
INFEXP	----	1.0 – 3.0	2.0	2.0
INFILD	----	1.0 – 3.0	2.0	2.0
DEEPFR	----	0.0 – 0.50	0.0	0.1
BASETP	----	0.0 – 0.20	0.0 – 0.03	0.03 – 0.05
AGWETP	----	0.0 – 0.20	0.00	0.00
CEPSC	in	0.01 - 0.40	0.000 – 0.213	0.000 - 0.375
UZSN	in	0.05 – 2.0	0.427 – 9.548	0.313 – 3.300
NSUR	----	0.10 – 0.50	0.05 – 0.30	0.048 – 0.576
INTFW	----	1.0 – 10.0	0.56 – 1.69	2.0
IRC	1/day	0.30 – 0.85	0.55 – 0.70	0.55 – 0.70
LZETP	----	0.1 – 0.9	0.132 – 0.900	0.189 – 0.930
RETSC	in	0.0 – 1.0	0.001 – 0.05	0.001 – 0.05
KS	----	0.0 – 0.9	0.5	0.5

Continuously monitored flow data was not available within the Gills Creek watershed. Instead, a continuous flow record was established utilizing the continuous flow record from USGS Station #02056900 located on the Blackwater River just upstream of the confluence of Maggodee Creek. In order to relate flow values measured at USGS Station #02056900 (i.e. the nearest continuous flow record) to flows at the VADEQ Station #4AGIL008.30, a regression analysis was performed on instantaneous measurements of flow at both locations. These measurements were recorded as part of a special study conducted by VADEQ. The resulting relationship was:

$$Q_{4AGIL008.30} = 0.328 * (Q_{USGS\ Gage})^{0.949}$$

This relationship was used to transform continuously recorded flows from USGS Station #02056900 to VADEQ station #4AGIL008.30 within the Gills Creek impairment and create a continuous flow record for use during calibration and validation (Figure 4.4).

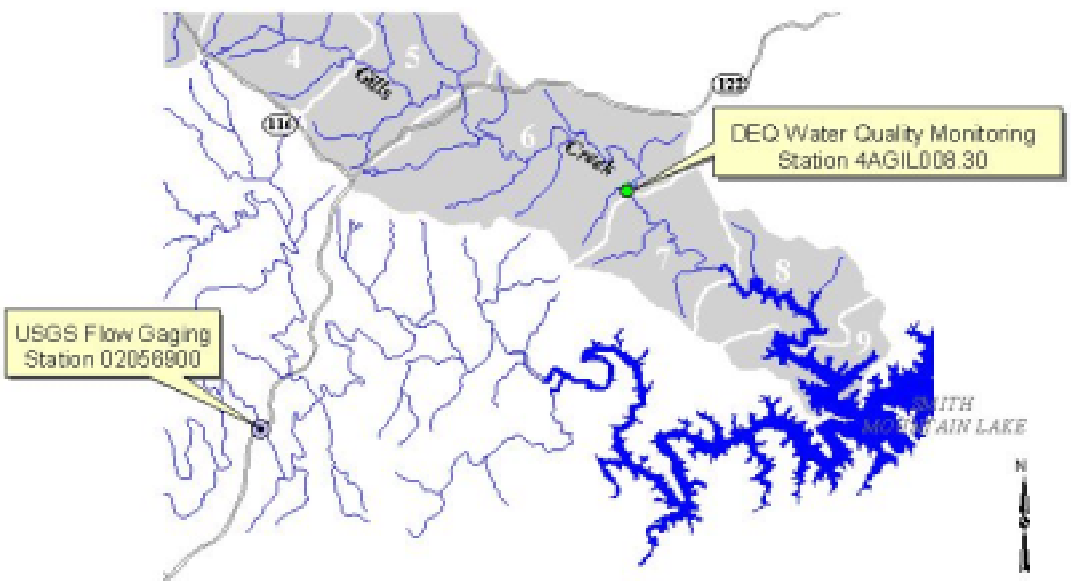

Figure 4.4 Location of monitoring stations used to transform continuous flow data from USGS Station #02056900 to VADEQ Station #4GIL008.30

The model was calibrated for hydrologic accuracy using the 30-minute flow data transformed from USGS Station #02056900 for the period October 1994 through September 1998 (Table 4.6). Results for the entire calibration period are plotted in Figure 4.5. Water year 1998 is represented in Figure 4.6 to portray the model performance on an annual scale. Positive values for "% Error" indicated the model is over estimating the flow conditions and conversely negative values indicate under estimates of observe data.

Table 4.6 Hydrology calibration criteria and model performance for period 10/1/94 through 9/30/98.

Criterion	Simulated	Observed	% Error
Total runoff, in	67.41	62.22	8.34
Low flow recession rate	0.97	0.97	0.00
Total of lowest 50% of flows, in	12.23	13.18	-7.21
Total of highest 10% of flows, in	21.89	22.34	-2.01
Total storm volume, in	4.80	5.45	-11.93
Summer flow volume, in	11.16	12.26	-8.97
Winter flow volume, in	23.04	21.97	4.87
Summer storm volume, in	1.45	1.33	9.02

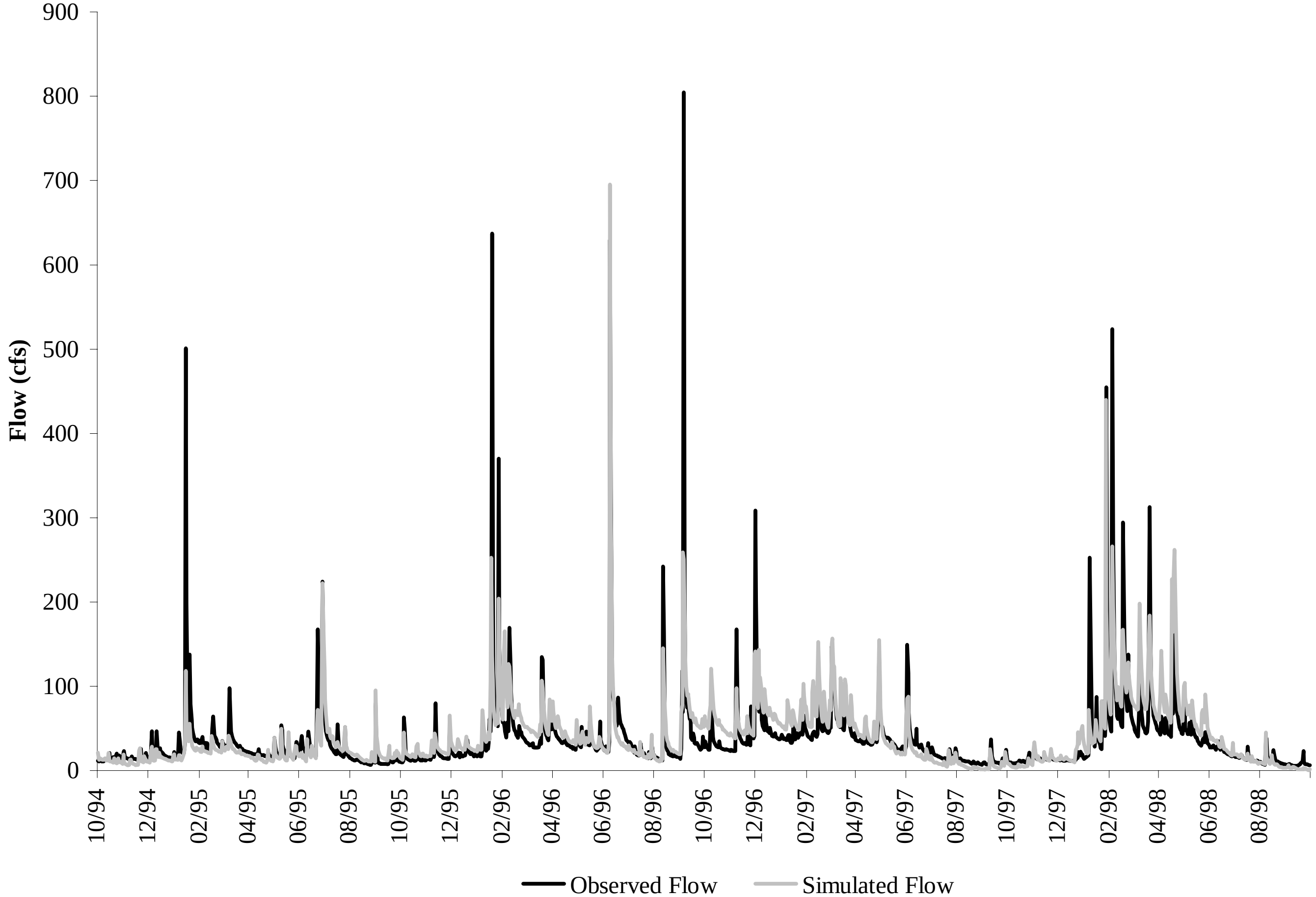

Figure 4.5 Calibration results for period 10/1/94 through 9/30/98.

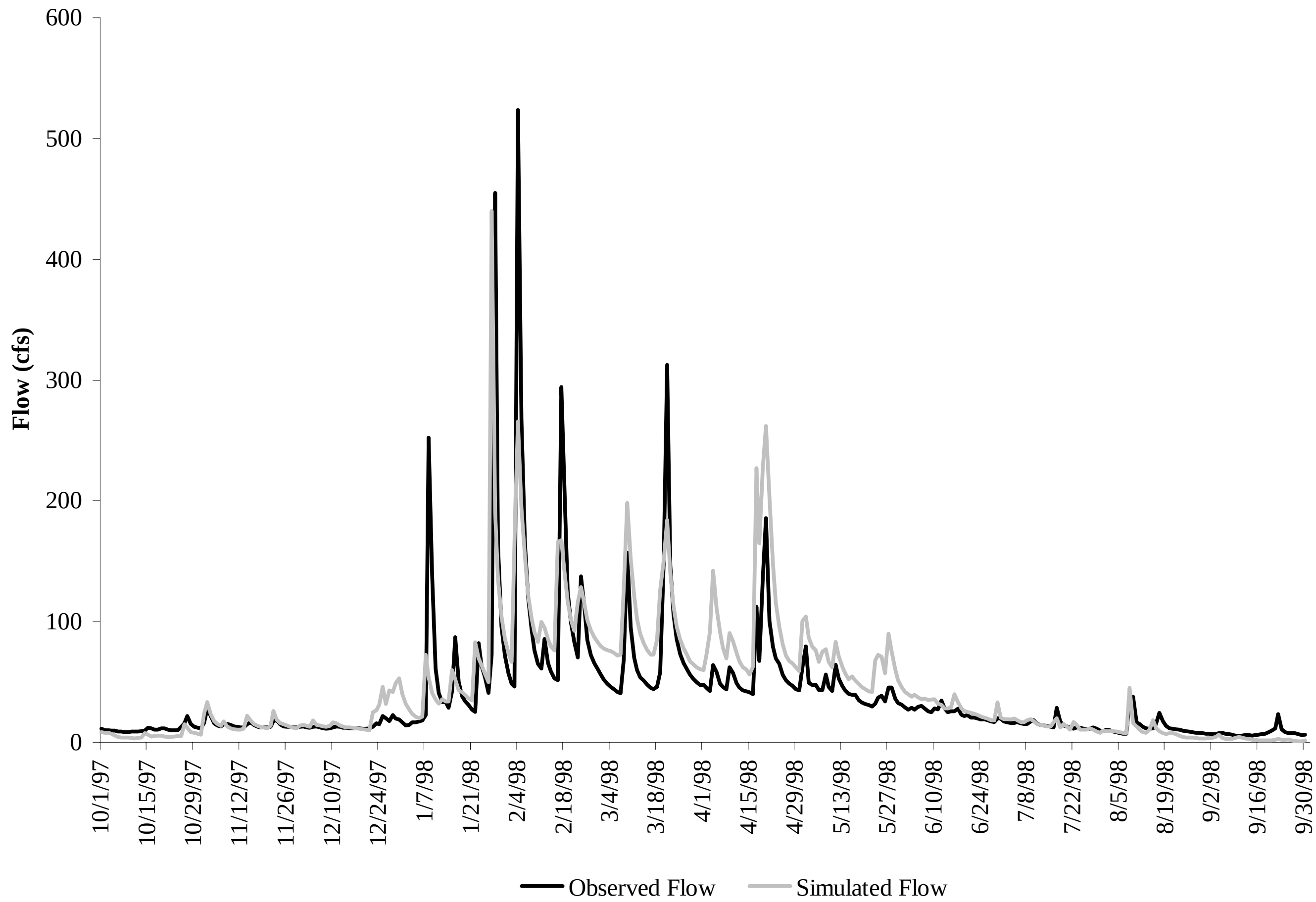

Figure 4.6 Calibration results for period 10/1/97 through 9/30/98.

The model was validated for the period January 1991 through September 1994 and October 1980 through September 1981 (Table 4.7). Only mean daily flows were available for this period. Validation results are included in Figure 4.7 through Figure 4.9.

Table 4.7 Hydrology validation criteria and model performance for validation period 1/1/91 through 9/30/94 and 10/1/80 through 9/30/81.

Criterion	Simulated	Observed	% Error
Total runoff, in	59.78	65.17	-8.27
Low flow recession rate	0.96	0.965	-0.52
Total of lowest 50% of flows, in	11.79	14.67	-19.63
Total of highest 10% of flows, in	18.71	22.61	-17.25
Total storm volume, in	6.43	6.72	-4.31
Summer flow volume, in	11.25	13.00	-13.46
Winter flow volume, in	16.74	17.12	-2.22
Summer storm volume, in	0.60	0.62	-3.22

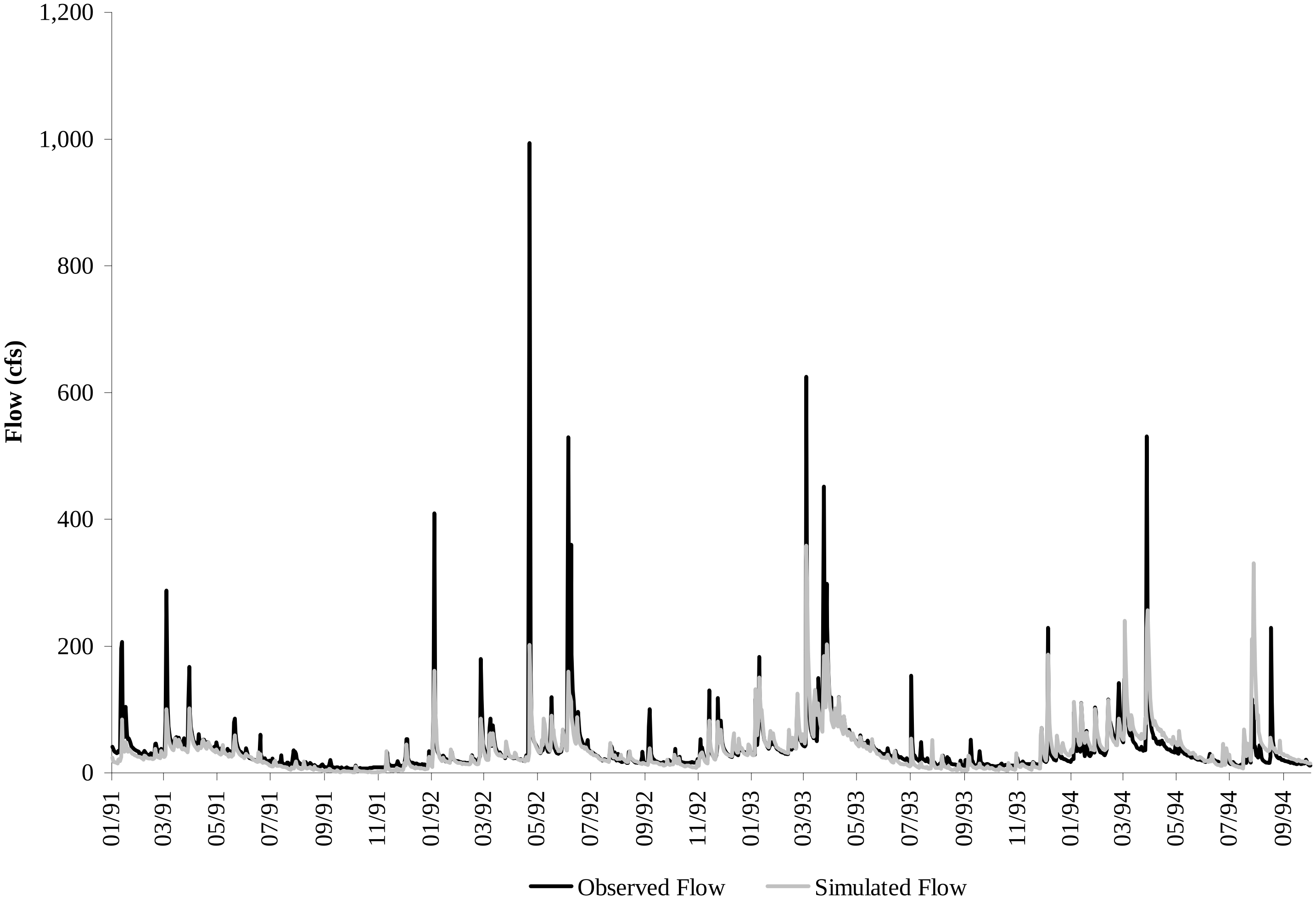

Figure 4.7 **Validation results for period 1/1/91 through 9/30/94.**

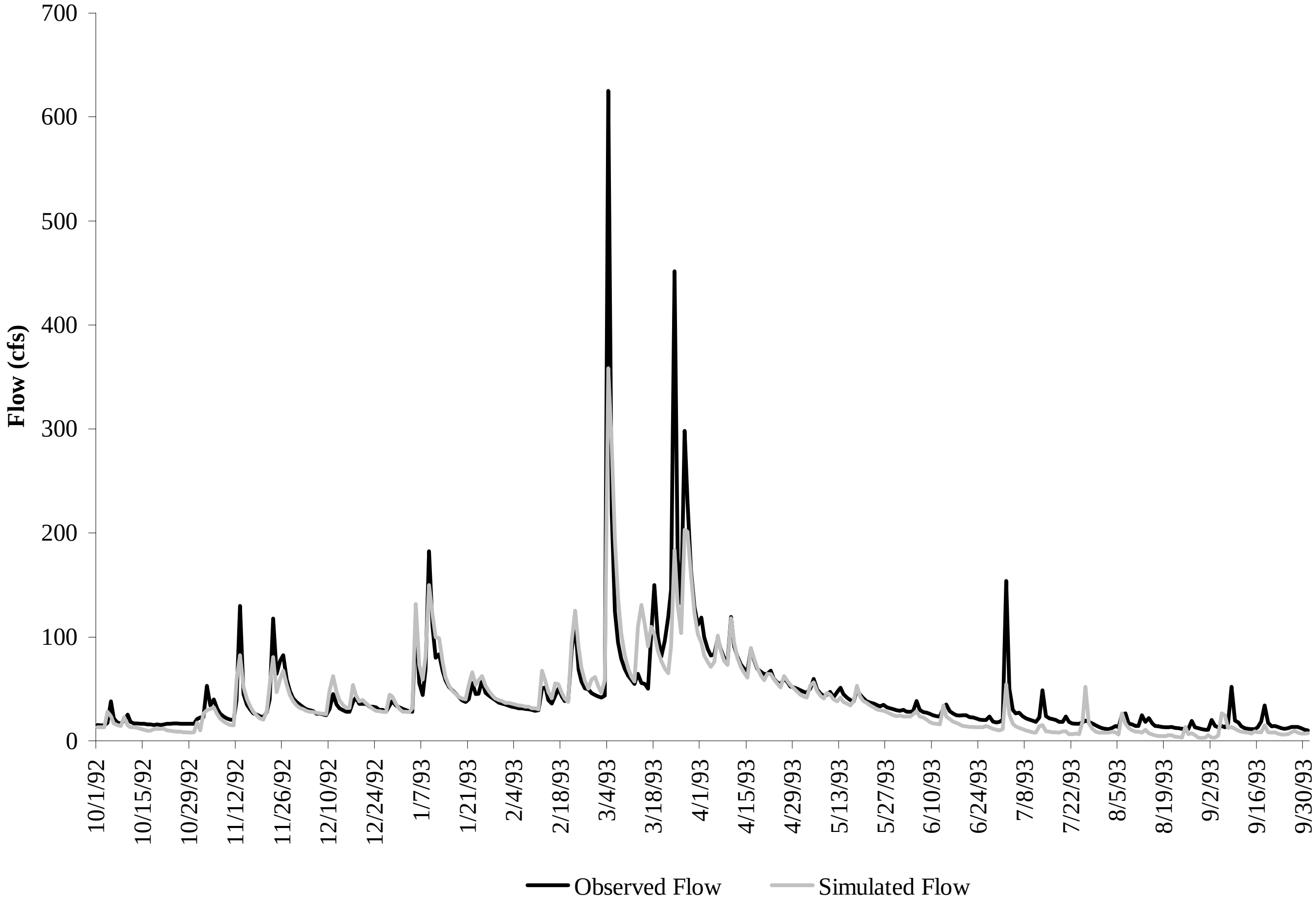

Figure 4.8 Validation results for period 10/1/92 through 9/30/93.

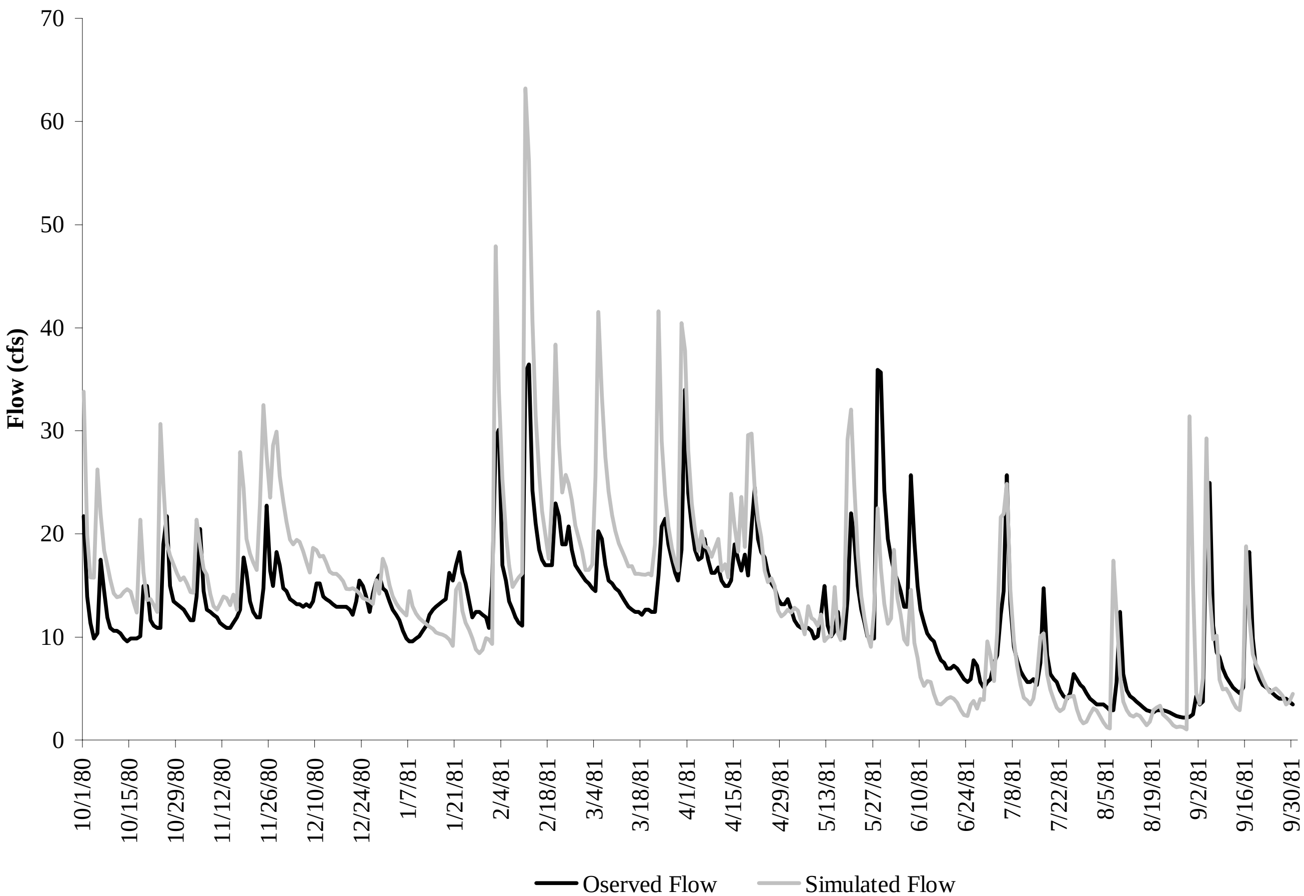

Figure 4.9 Validation results for period 10/1/80 through 9/30/81.

4.6.2 Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (e.g. fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Grab samples are collected at a specific point in time and space, while the model predicts concentrations averaged over the entire stream reach and the duration of the time-step, in this case 15 minutes. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (over 8,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

The water quality calibration was conducted from 1/1/93 through 12/31/95. Four parameters were utilized for adjustment in the model; in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP), and concentration of fecal coliform in interflow (IOQC). Additional model parameters that adjustment was deemed not applicable or exhibited a minor model response were: rate of accumulation on land (ACQOP), concentration in groundwater flow (AOQC), initial concentration of fecal coliform (DQAL), and the temperature correction coefficient (THFST). All these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits in an effort to establish an acceptable match between measured and modeled fecal coliform concentrations (Table 4.8). With the exception of the first-order decay rate, all of the parameters listed above influence only land-based loadings. Figures 4.10 through 4.12 show the results of calibration. Short-period fluctuations in the modeled data denotes the effective modeling of the variability within daily concentrations that was achieved through distributing direct depositions from wildlife, livestock, and uncontrolled discharges across each day (Section 4.3).

Table 4.8 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
ACQOP	FC/ac·day	0.0E+00 – 1.0E+20	49.0E+06 – 9.0E+10	49.0E+06 – 9.0E+10
SQOLIM	FC/ac	1.0E-02 – 1.0E+30	1.0E+08 – 4.0E+12	1.0E+08 – 17.0E+12
WSQOP	in/hr	0.05 – 3.00	0.2 – 0.6	0.3 – 0.9
IOQC	FC/ft^3	0.0E+00 – 1.0E+06	1.0E+01 – 1.0E+03	1.0E+02 – 9.0E+04
AOQC	FC/ft^3	0.0 – 10.0	0.0	0.0
DQAL	FC/100ml	0.0 – 1,000.0	85.0 – 566.0	85.0 – 566.0
FSTDEC	1/day	0.01 – 10.00	0.50 – 6.00	0.25 – 1.00
THFST	---	1.00 – 2.00	1.07	1.07

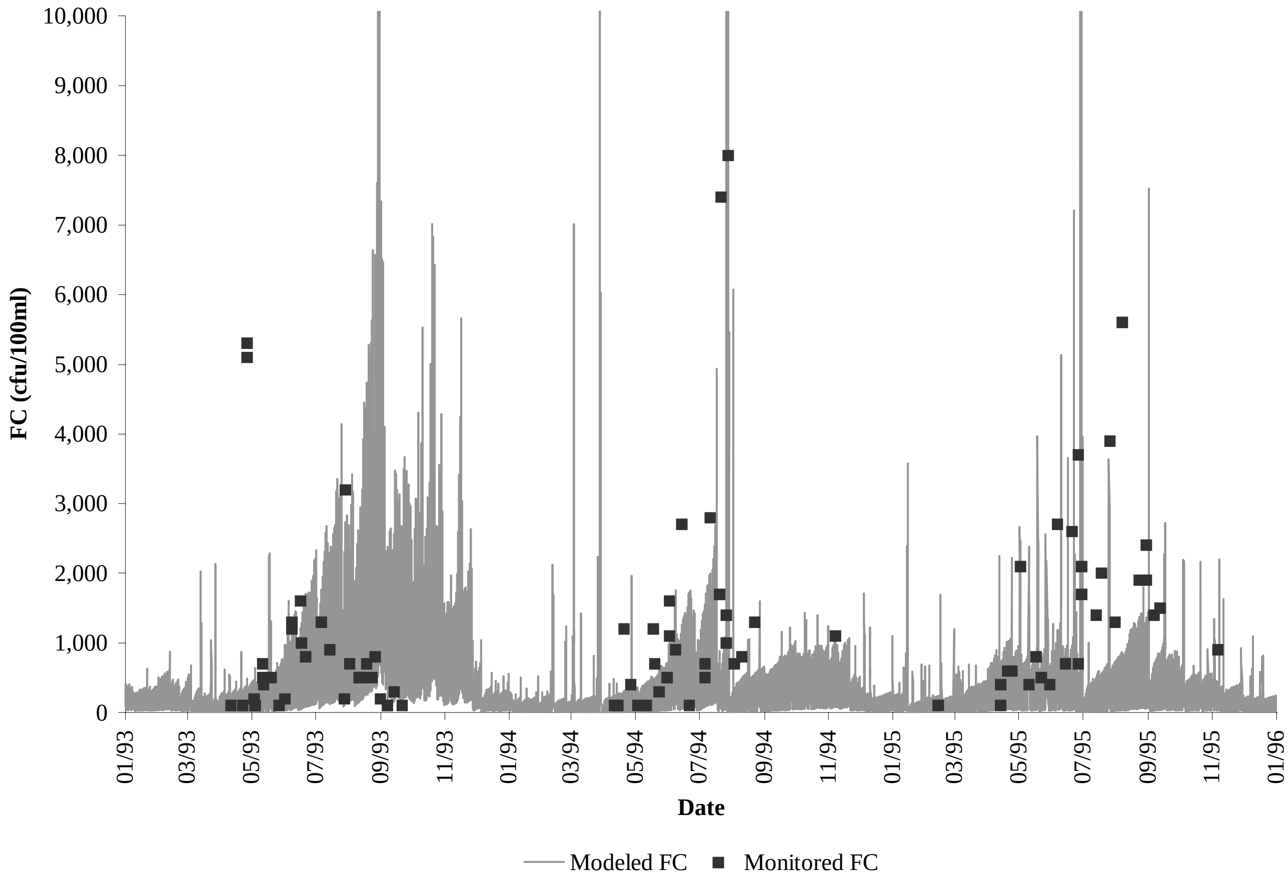

Figure 4.10 Quality calibration for subwatershed 1 of Gills Creek impairment.

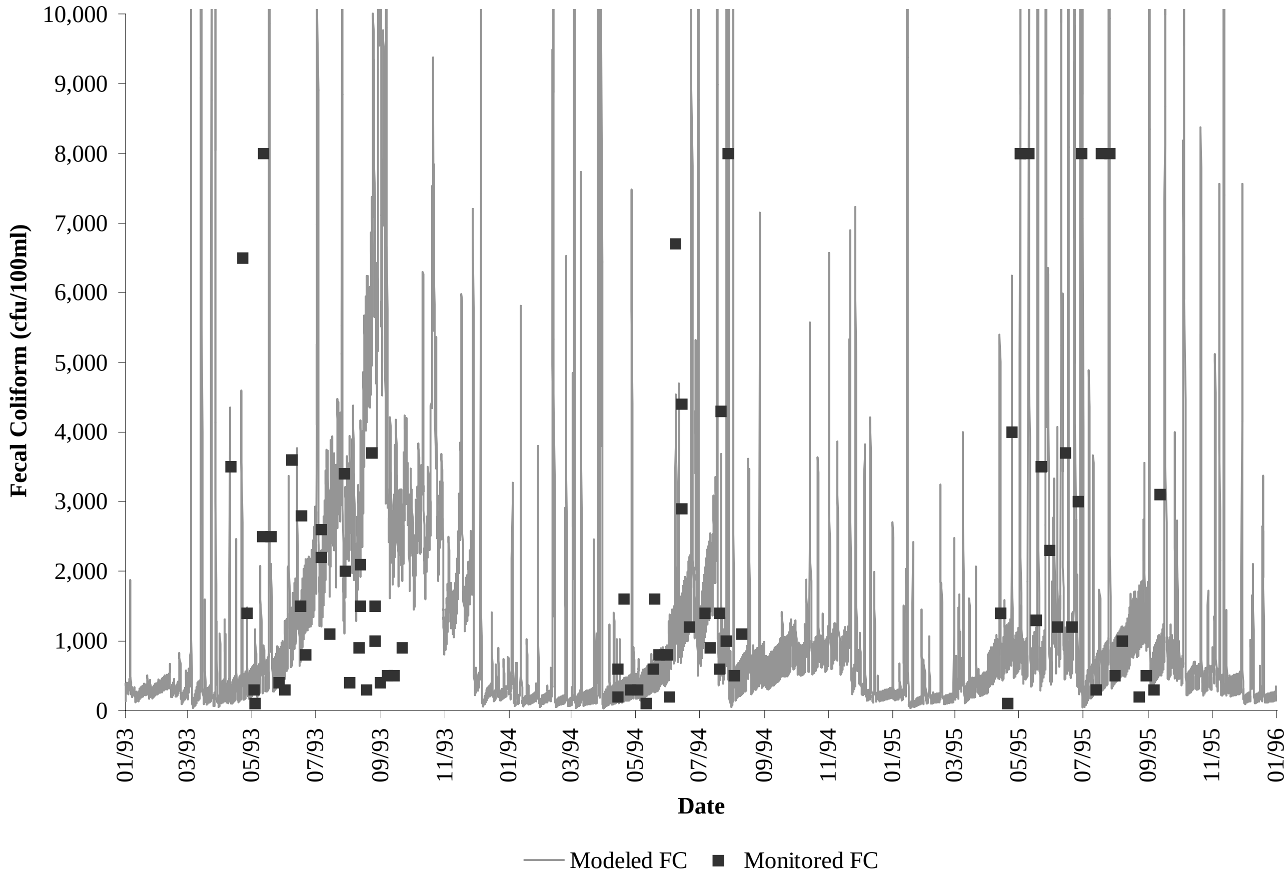

Figure 4.11 Quality calibration for subwatershed 6 of Gills Creek impairment.

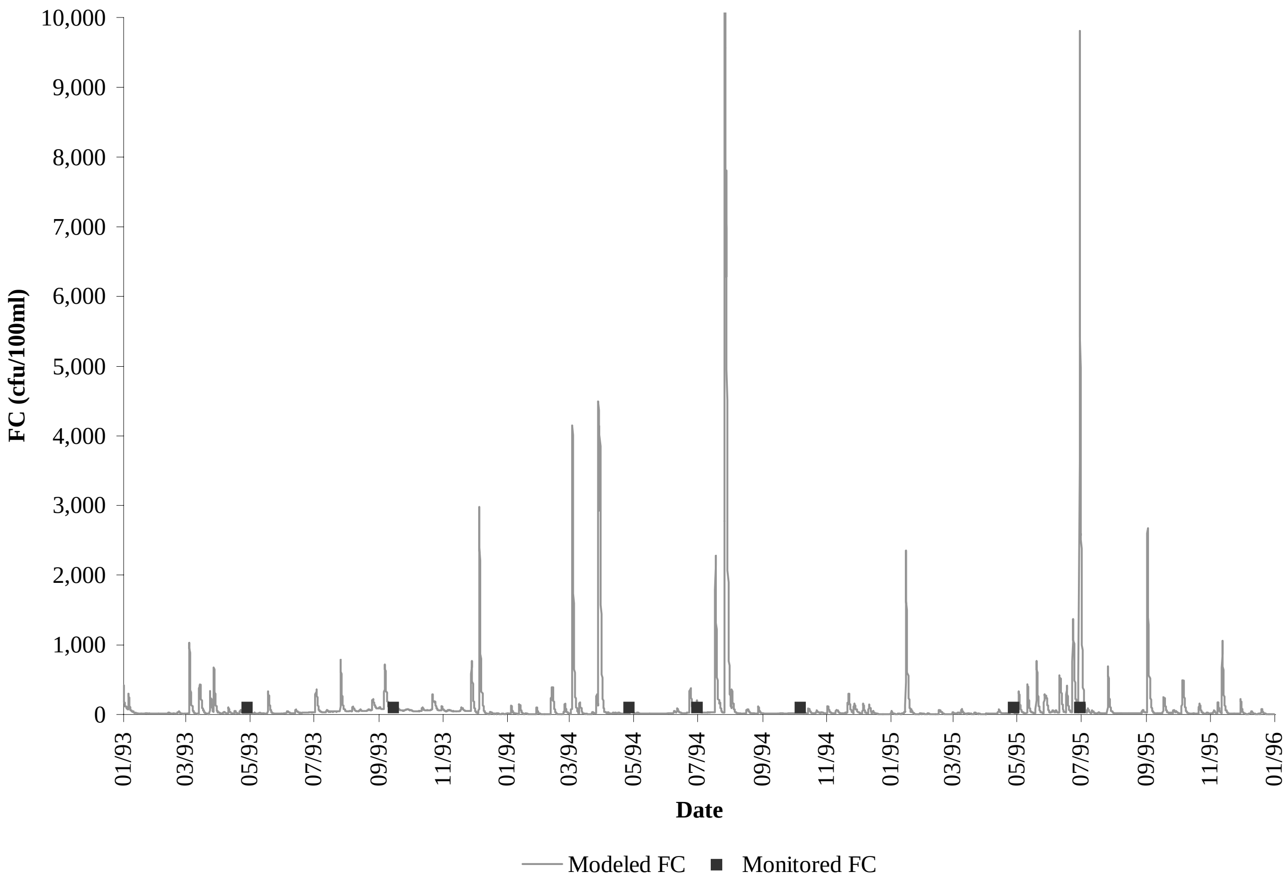

Figure 4.12 Quality calibration for subwatershed 8 of Gills Creek impairment.

Careful visual inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. First, the minimum and maximum modeled values in each modeled window was determined. Figures 4.13 through 4.15 show the relationship between these extreme values and observed data. In addition, standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{(n-1)}}}{\sqrt{n}}$$

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2 - day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2 - day window} \end{aligned}$$

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and therefore increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data (Section 2) and found to be at reasonable levels (Table 4.9).

Table 4.9 Results of analyses on calibration runs.

WQ Monitoring Station	Subwatershed	Mean Standard Error (cfu/100ml)	Max. Simulated Value (cfu/100ml)
4AGIL023.22	1	116.37	56,640
4AGIL008.30	6	235.00	173,870
4AGIL002.39	8	63.86	17,689

The water quality validation was conducted for the period from 1/1/92 to 12/31/92. The relationship between observed values and modeled values is illustrated in Figures 4.16 through 4.21. The results of standard error and maximum value analyses are reported in Table 4.10. Standard errors calculated from validation runs were comparable to standard errors calculated from calibration runs. Maximum simulated values were comparable to observed maximum values in the area (Section 2).

Table 4.10 Results of analyses on validation runs.

WQ Monitoring Station	Subwatershed	Mean Standard Error (cfu/100ml)	Max. Simulated Value (cfu/100ml)
4AGIL023.22	1	53.49	29,552
4AGIL008.30	6	232.97	123,630
4AGIL002.39	8	4.17	7,920

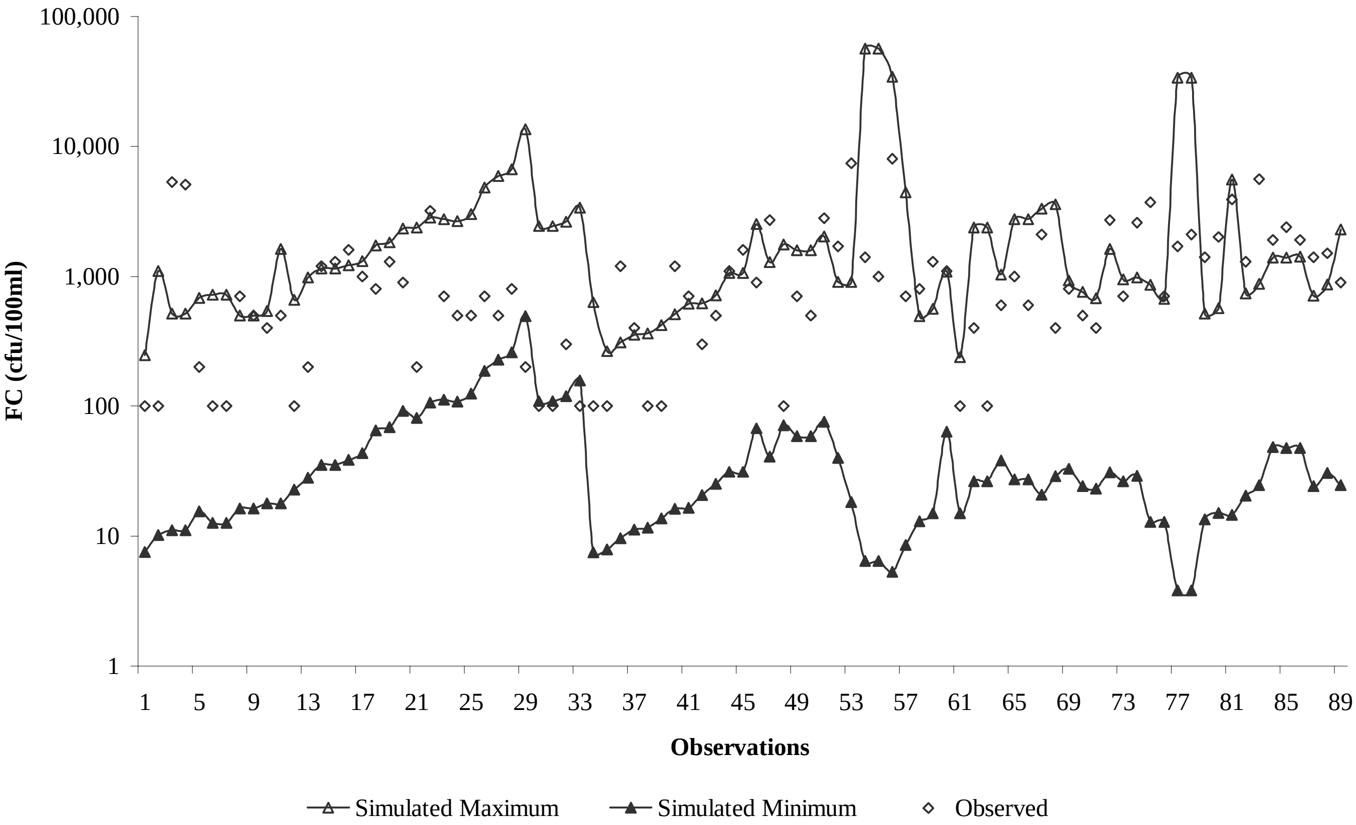

Figure 4.13 Comparison of minimum and maximum modeled values in a 2-day window centered on a single observed value. Calibration period for subwatershed 1 in Gills Creek impairment.

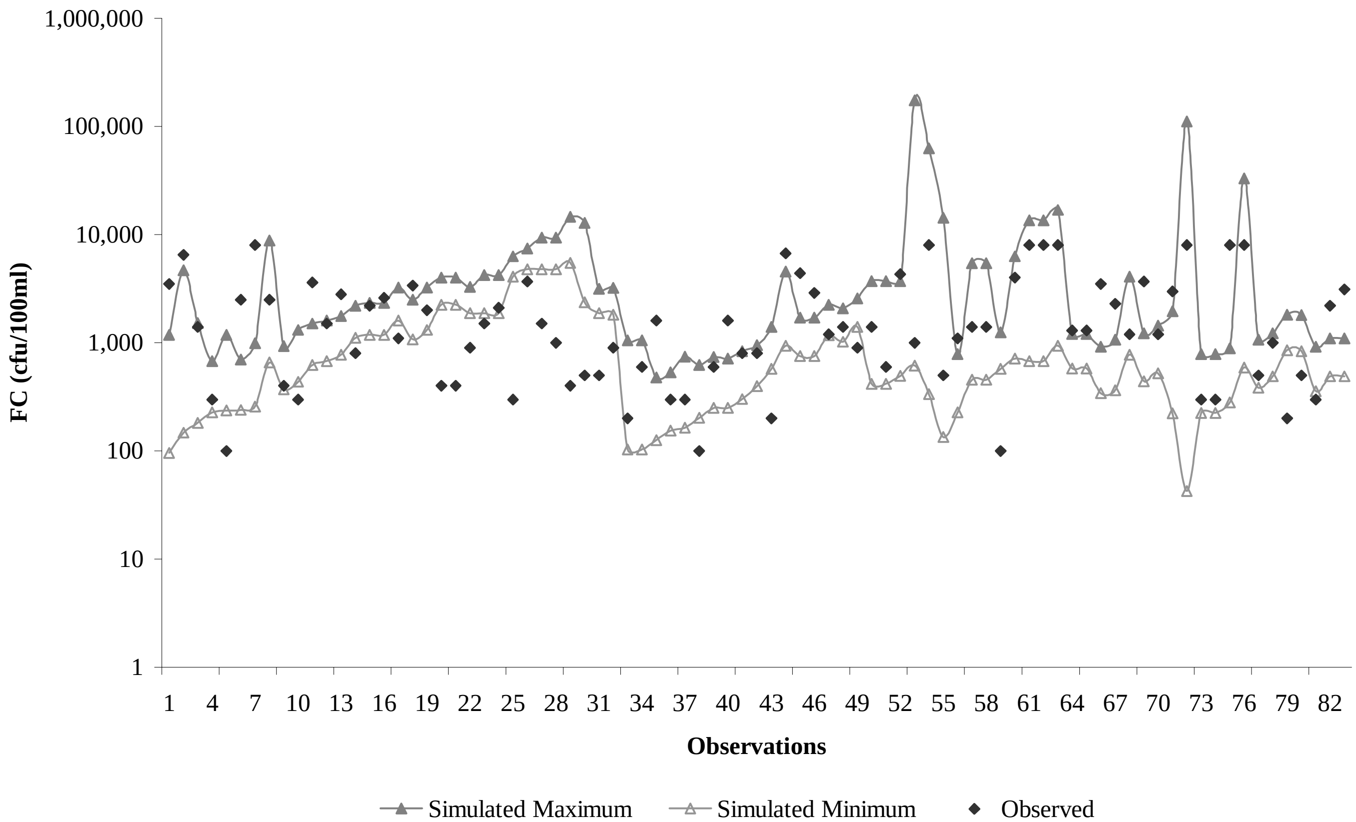

Figure 4.14 Comparison of minimum and maximum modeled values in a 2-day window, centered on a single observed value. Calibration period for subwatershed 6 in Gills Creek impairment.

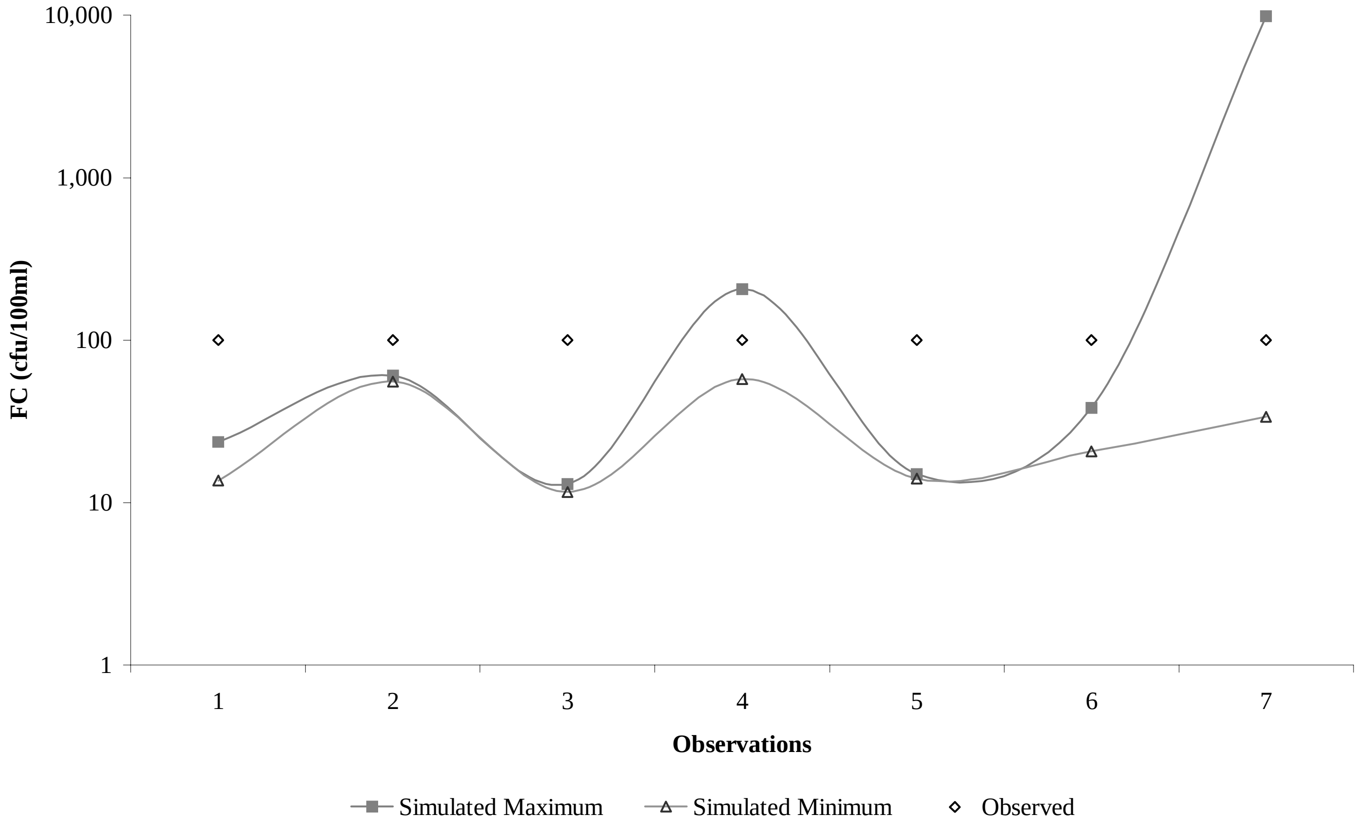

Figure 4.15 Comparison of minimum and maximum modeled values in a 2-day window, centered on a single observed value. Calibration period for subwatershed 8 in Gills Creek impairment.

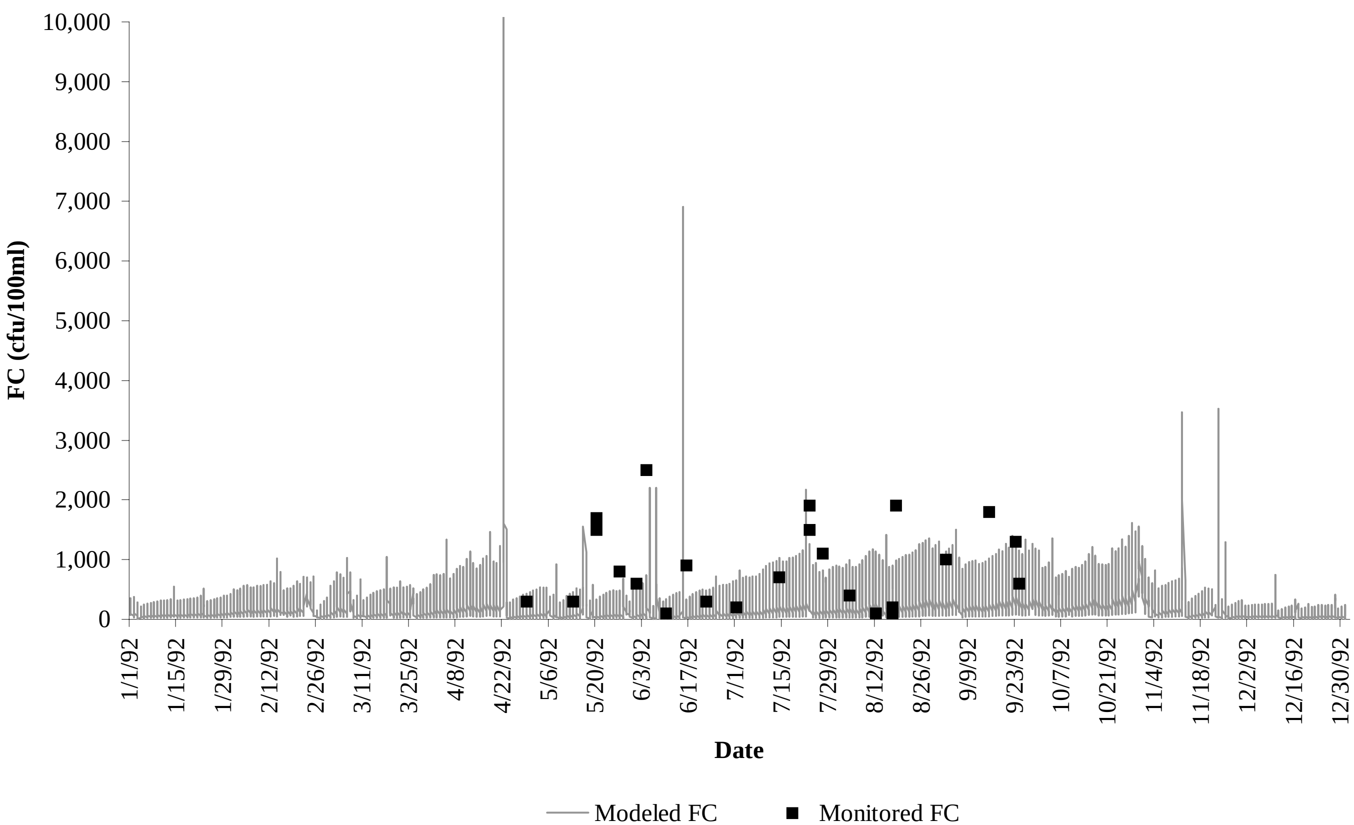

Figure 4.16 Quality validation for subwatershed 1 of Gills Creek impairment.

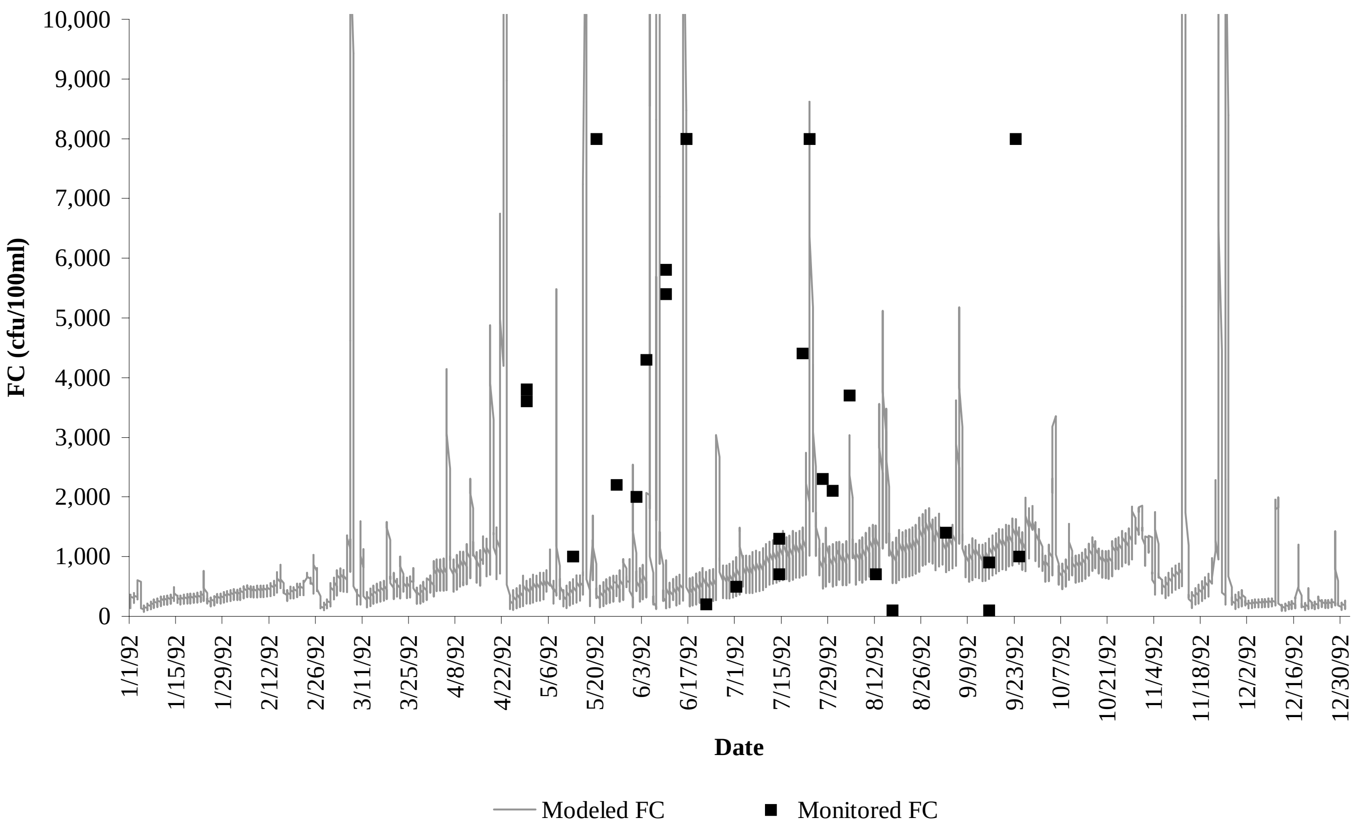

Figure 4.17 Quality validation for subwatershed 6 of Gills Creek impairment.

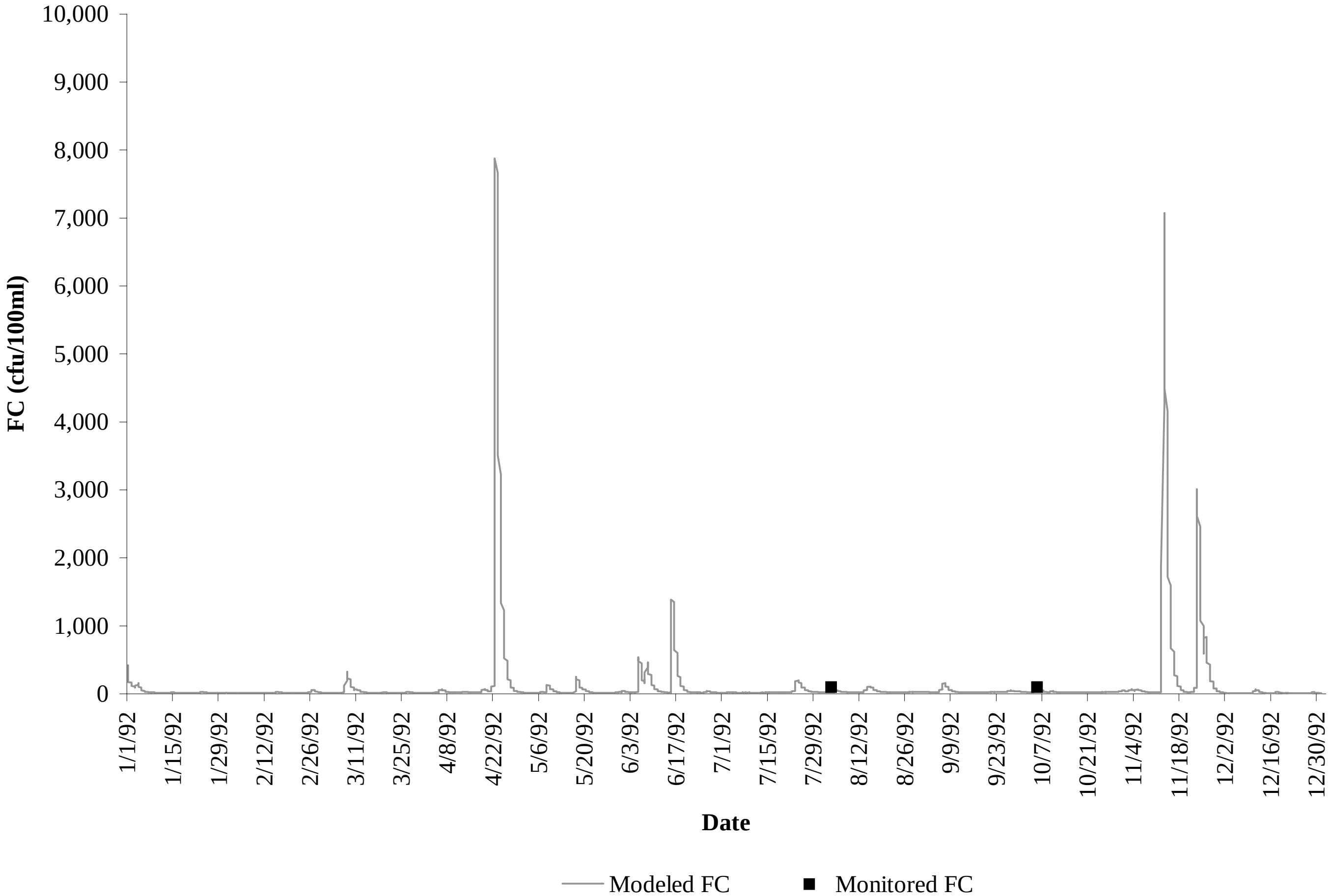

Figure 4.18 Quality validation for subwatershed 8 of Gills Creek impairment.

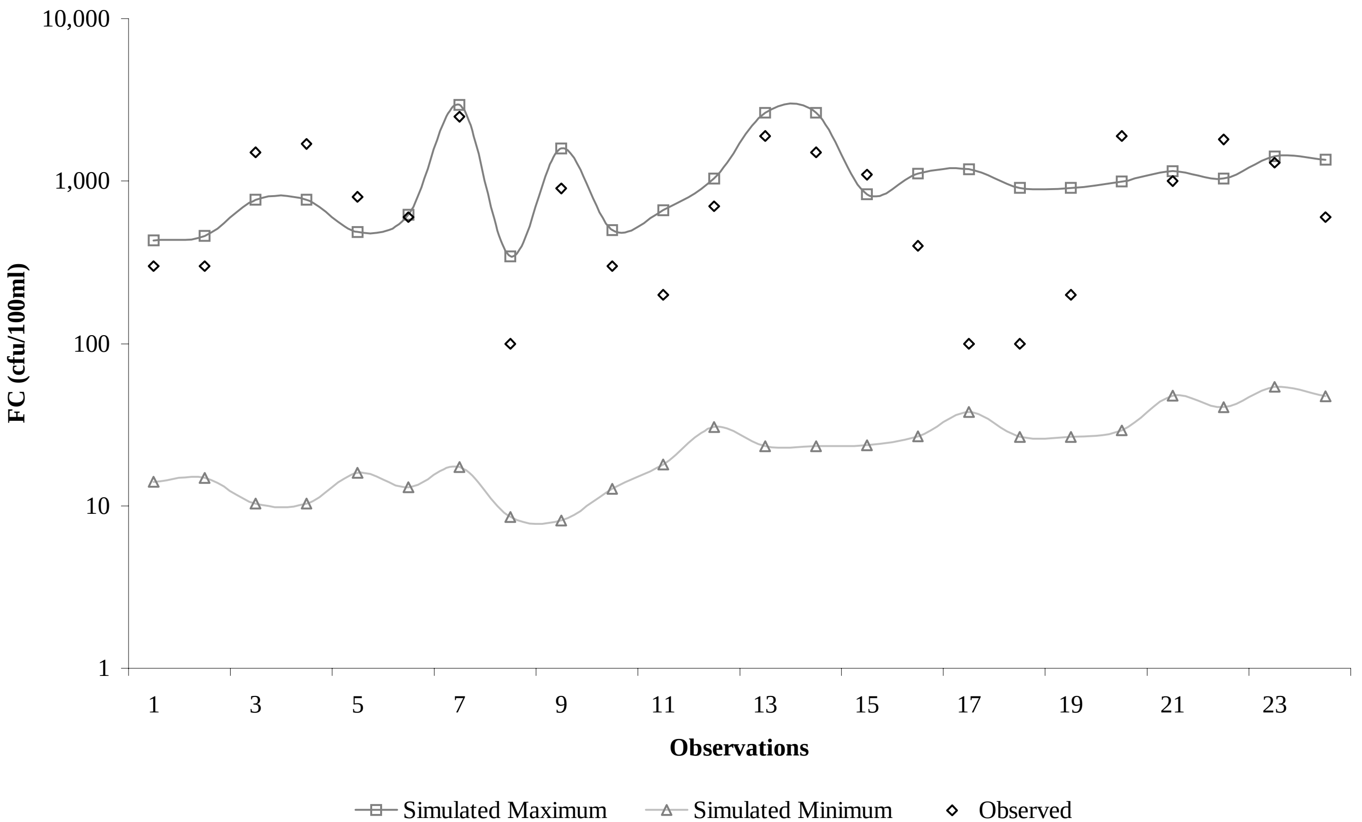

Figure 4.19 Comparison of minimum and maximum modeled values in a 2-day window, centered on a single observed value. Validation period for subwatershed 1 of Gills Creek impairment

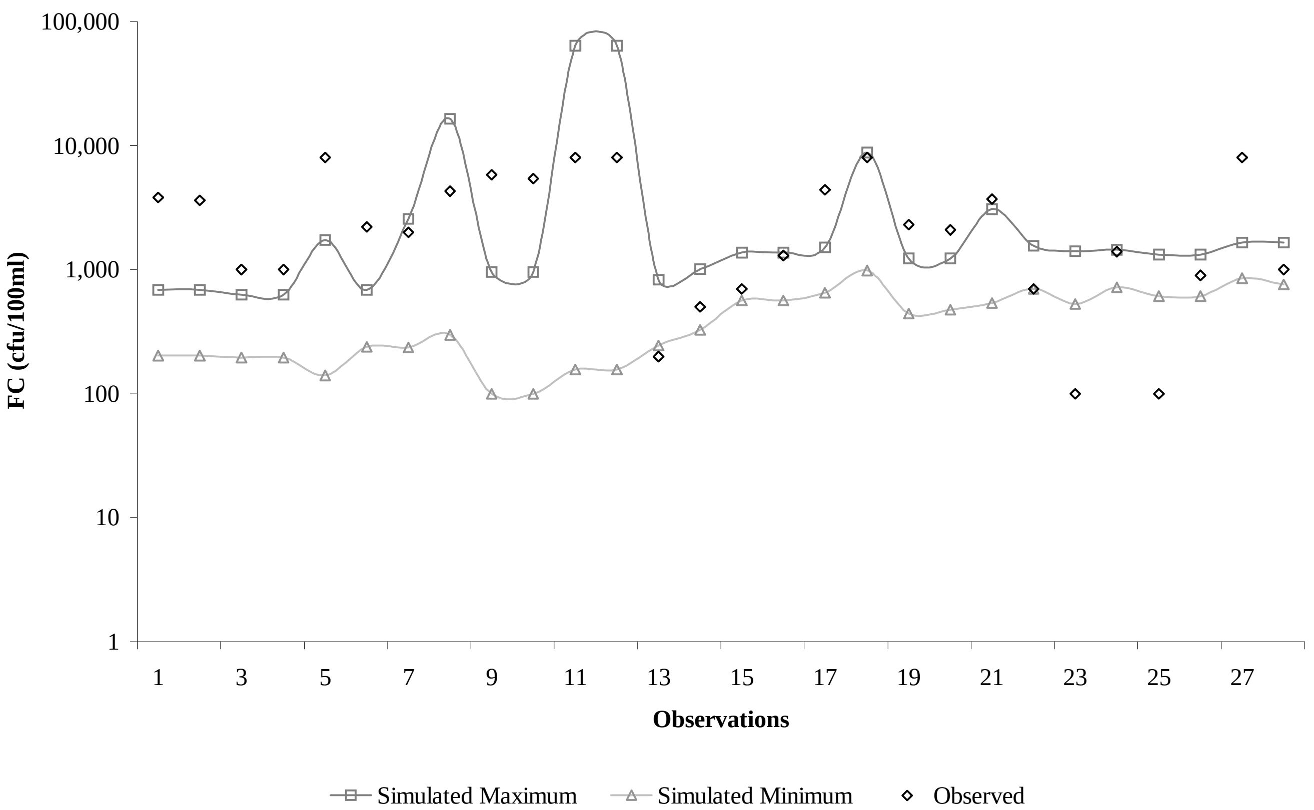

Figure 4.20 Comparison of minimum and maximum modeled values in a 2-day window, centered on a single observed value. Validation period for subwatershed 6 of Gills Creek Impairment.

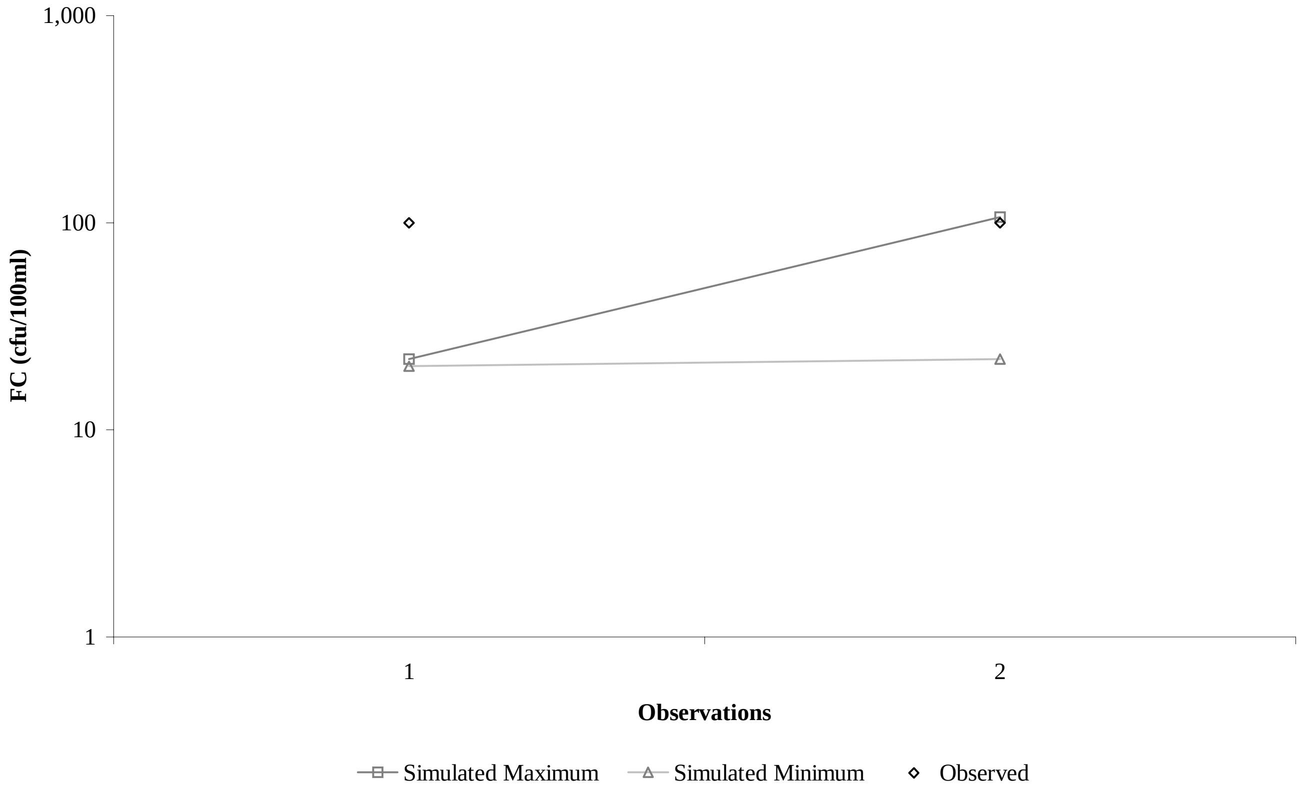

Figure 4.21 Comparison of minimum and maximum modeled values in a 2-day window, centered on a single observed value. Validation period for subwatershed 8 of Gills Creek impairment

4.7 Existing Loadings

All appropriate inputs were updated to 2001 conditions, as described in Section 4. All remaining model runs were conducted using precipitation data for a representative period used during water quality calibration and validation (1/1/92 through 12/31/96). Figures 4.22 and 4.23 show the 30-day geometric mean of fecal coliform concentrations in relation to the 200 cfu/100 ml standard.

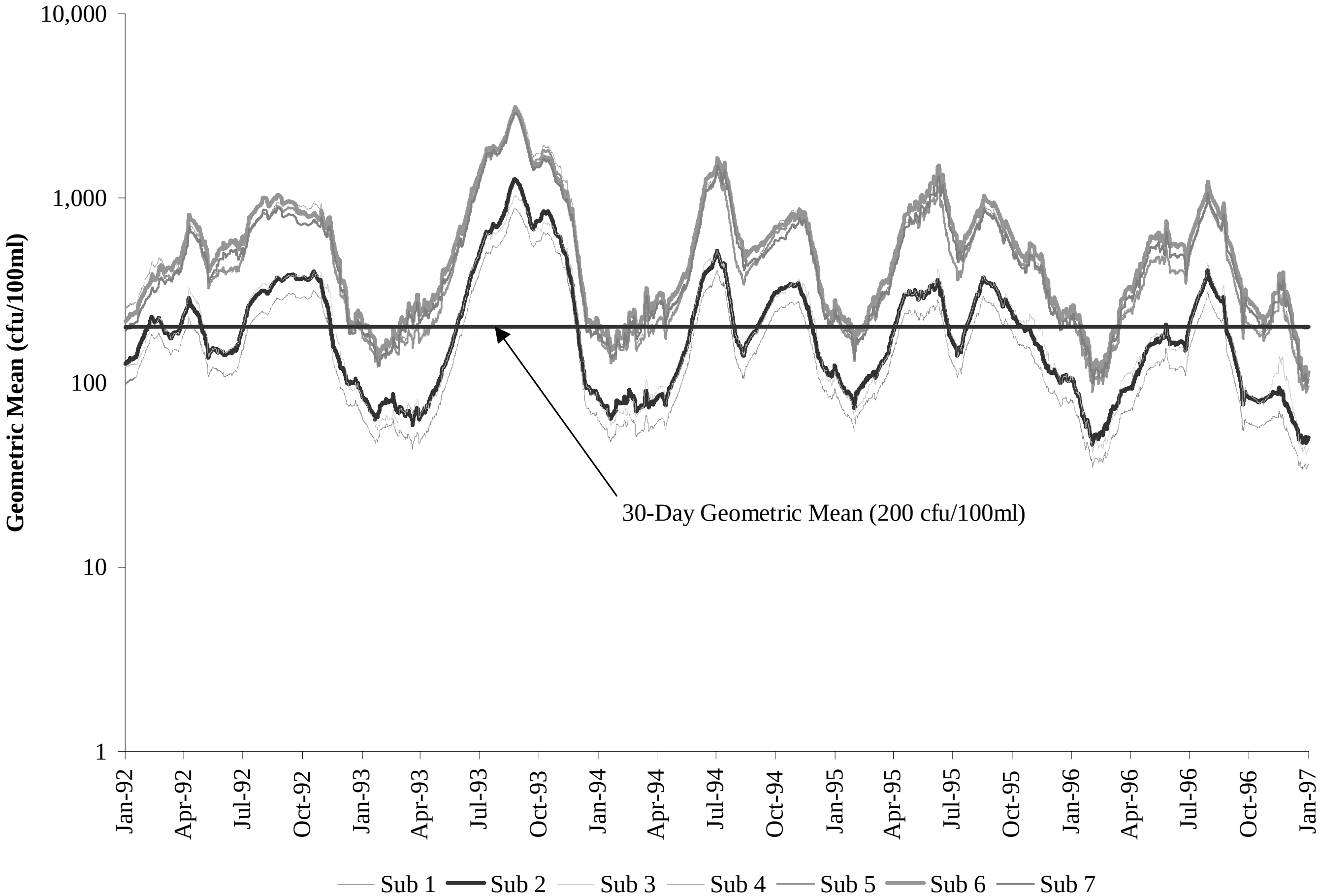

Figure 4.22 Existing conditions in subwatersheds 1-7 of Gills Creek impairment.

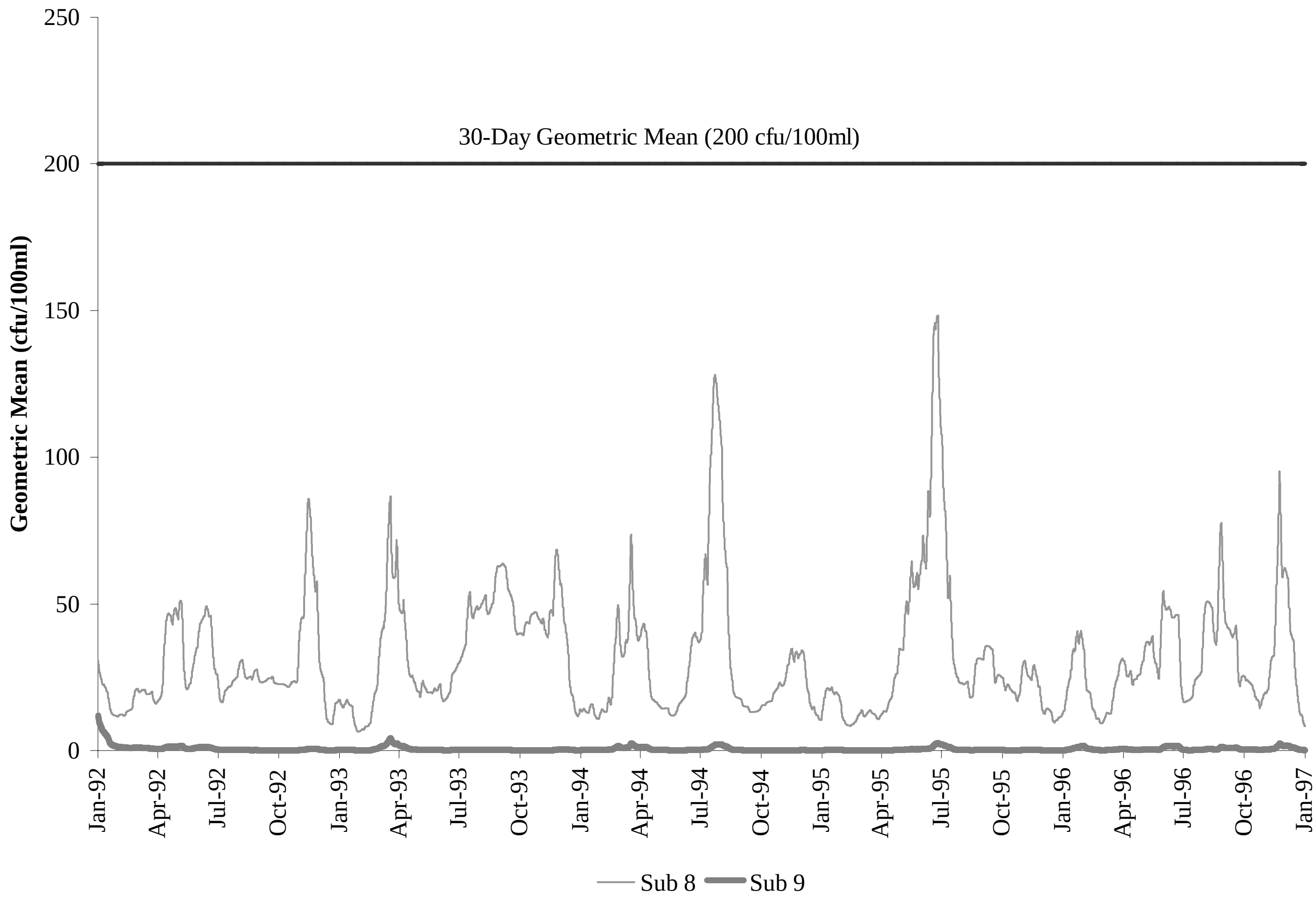

Figure 4.23 Existing conditions in subwatersheds 8 and 9 of Gills Creek impairment.

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, i.e. point sources) and load allocations (LAs, i.e. nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (e.g. accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For fecal coliform bacteria, TMDL is expressed in terms of counts (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Sensitivity Analysis

Sensitivity analyses were conducted first, to assess the sensitivity of the model to changes in hydrologic and water quality parameters then, to assess the impact of unknown variability in source allocation (e.g., seasonal and spatial variability of waste production rates for wildlife, livestock and septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

Sensitivity analysis is useful to gain an understanding of what parameters are most important for the model, and how well each parameter must be estimated to provide certain accuracy. An initial base run was simulated using HSPF and statistical results from HSPEXP were recorded (Table 5.1). A parameter value was then changed from the base value by a percentage, holding all other parameters constant, and the resulting statistics were recorded. The percent change from the base statistics was calculated. This procedure was repeated for a range of positive and negative parameter percent changes for all parameters affecting the hydrologic response of HSPF (Table 5.2).

Table 5.1 Base parameter values used to determine hydrologic model response.

Parameter	Units	Description	Base Value
LZSN	in	Lower Zone Nominal Storage	15.0
INFILT	in/hr	Soil Infiltration Capacity	0.059-0.262
DEEPFR	---	Fraction of Deep Groundwater	0.1
BASETP	---	Base Flow Evapotranspiration	0.03-0.05
INTFW	---	Interflow Inflow	2.0
MON-INTERCEP	in	Monthly Interception Storage Capacity	0.0-0.375
MON-UZSN	in	Monthly Upper Zone Nominal Storage	0.313-3.300
MON-MANNING	---	Monthly Manning's *n* for Overland Flow	0.048-0.576
MON-LZETP	in	Monthly Lower Zone Evapotranspiration	0.189-0.930

Table 5.2 Sensitivity analysis results for hydrologic model parameters.

Model Parameter	Parameter Change (%)	% Change Total Annual Runoff	High Flows	Low Flows	Total Storm Volume	Interflow	Surface Flow	Summer Flow Volume	Winter Flow Volume	Summer Storm Volume
BASETP	-50.00	1.28	-2.06	9.48	-1.25	-4.13	-1.21	8.87	-2.04	-0.69
BASETP	-10.00	0.24	-0.41	1.88	-0.42	-0.85	-0.27	1.79	-0.39	0.00
BASETP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BASETP	10.00	-0.25	0.41	-1.96	0.21	0.81	0.22	-1.70	0.43	0.00
BASETP	50.00	-1.19	1.96	-9.24	1.04	4.13	1.21	-8.42	1.95	0.69
DEEPFR	-50.00	4.14	2.42	5.72	1.88	0.00	0.00	4.84	3.73	0.69
DEEPFR	-10.00	0.83	0.46	1.14	0.21	0.00	0.33	0.99	0.78	0.00
DEEPFR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DEEPFR	10.00	-0.83	-0.50	-1.14	-0.42	0.00	0.00	-0.90	-0.74	0.00
DEEPFR	50.00	-4.15	-2.47	-5.81	-2.08	-0.05	0.00	-4.75	-3.69	-1.38
INFILT	-50.00	0.56	14.71	-11.61	21.46	18.46	27.02	-5.20	7.77	23.45
INFILT	-30.00	0.22	7.04	-5.97	10.42	10.49	11.64	-2.78	3.82	12.41
INFILT	-10.00	0.04	1.96	-1.80	2.92	3.32	2.97	-0.81	1.09	3.45
INFILT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INFILT	10.00	-0.04	-1.69	1.64	-2.71	-3.23	-2.36	0.81	-0.91	-3.45
INFILT	30.00	-0.12	-4.52	4.58	-6.88	-9.21	-5.93	2.24	-2.47	-8.97
INFILT	50.00	-0.15	-6.99	7.20	-10.21	-14.71	-8.40	3.49	-3.73	-13.79
INTFW	-50.00	-1.32	-4.98	2.78	2.29	-38.44	15.05	0.00	-2.17	6.21
INTFW	-10.00	-0.19	-0.78	0.41	0.21	-5.22	1.92	-0.09	-0.26	0.69
INTFW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INTFW	10.00	0.15	0.69	-0.41	-0.42	4.41	-1.65	0.09	0.22	-0.69
INTFW	50.00	0.59	2.70	-1.55	-1.25	16.90	-6.15	0.54	0.87	-2.76
LZSN	-50.00	13.13	16.22	14.80	26.04	34.98	9.06	9.32	20.01	15.86
LZSN	-30.00	7.67	7.90	11.69	12.92	16.37	4.12	6.09	10.98	8.97
LZSN	-10.00	2.51	2.33	4.33	3.75	4.75	1.21	2.15	3.43	2.76
LZSN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LZSN	10.00	-2.48	-2.19	-4.82	-3.75	-4.18	-1.04	-2.51	-3.04	-2.76
LZSN	30.00	-7.25	-6.17	-14.31	-10.21	-11.72	-2.91	-7.80	-8.55	-8.28
LZSN	50.00	-11.84	-10.05	-23.06	-16.04	-18.51	-4.50	-13.35	-13.59	-13.10
MON-INTERCEP	-50.00	1.11	-1.83	7.60	-0.83	-0.24	-0.99	7.26	-2.13	0.69
MON-INTERCEP	-10.00	0.18	-0.32	1.23	-0.21	-0.05	-0.16	1.16	-0.35	0.00
MON-INTERCEP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-INTERCEP	10.00	-0.18	0.32	-1.31	0.00	0.19	0.16	-1.08	0.39	0.00
MON-INTERCEP	50.00	-0.74	1.32	-5.23	0.00	0.57	0.66	-4.84	1.69	-1.38
MON-LZETP	-50.00	6.25	9.09	4.09	8.13	14.38	4.72	2.69	8.94	5.52
MON-LZETP	-30.00	2.43	3.24	1.96	2.92	4.94	1.54	1.25	3.34	2.07
MON-LZETP	-10.00	0.49	0.59	0.49	0.63	0.90	0.27	0.36	0.69	0.69
MON-LZETP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-LZETP	10.00	-0.42	-0.46	-0.49	-0.63	-0.76	-0.22	-0.27	-0.52	-0.69
MON-LZETP	30.00	-0.77	-0.87	-0.90	-1.04	-1.33	-0.44	-0.54	-0.95	-0.69
MON-LZETP	50.00	-0.96	-1.14	-1.06	-1.25	-1.66	-0.55	-0.63	-1.22	-0.69
MON-MANNING	-50.00	0.18	2.19	-0.82	6.25	-3.42	8.46	0.81	0.30	11.72
MON-MANNING	-10.00	0.01	0.32	-0.16	0.83	-0.47	1.15	0.09	0.04	2.07
MON-MANNING	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-MANNING	10.00	-0.03	-0.23	0.08	-0.83	0.38	-1.04	-0.09	0.00	-1.38
MON-MANNING	50.00	-0.09	-0.91	0.33	-3.54	1.66	-4.01	-0.36	-0.13	-6.21
MON-UZSN	-50.00	4.95	17.72	0.90	27.08	28.29	13.89	15.59	4.25	46.21
MON-UZSN	-30.00	2.64	8.54	1.14	13.13	13.81	6.32	8.06	2.47	24.83
MON-UZSN	-10.00	0.80	2.42	0.49	3.75	3.89	1.70	2.33	0.82	7.59
MON-UZSN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MON-UZSN	10.00	-0.77	-2.10	-0.57	-3.54	-3.42	-1.43	-2.06	-0.74	-6.90
MON-UZSN	30.00	-2.18	-5.53	-1.80	-9.17	-9.02	-3.68	-5.91	-2.04	-17.93
MON-UZSN	50.00	-3.47	-8.36	-3.11	-13.54	-13.57	-5.38	-9.14	-3.26	-26.90

In order to determine the HSPF water quality response, a similar procedure was followed. Parameters affecting FC delivery and die-off were set to the values established during calibration. This model was run using HSPF forming the output for the base run (Table 5.3). Outputted 15-minute in-stream FC concentrations were recorded. A running 30-day geometric mean was calculated at each 15-minute time-step and the maximum value for each month was recorded. As described above, a parameter value was changed, the model was run with the adjusted value and the resulting maximum 30-day geometric mean for each month was calculated. Difference in the maximum geometric mean per month from the base run was calculated for each parameter change (Table 5.4, Figures 5.1 – 5.4).

Table 5.3 Base parameter values used to determine water quality model response.

Parameter	Description	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	1.0E+08 – 17.0E+12
WSQOP	Wash-off Rate for FC on Land Surface	0.3 – 0.9
MON-IFLW-CONC	FC Interflow Concentration	1.0E+02 – 9.0E+04
FSTDEC	In-stream First Order Decay Rate	0.25 – 1.00

Table 5.4 Percent change in average monthly FC geometric mean for the years 1993-1995.

Model Parameter	Parameter Change (%)	Percent Change in average Monthly FC Geometric Mean 1993 -1995											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	13.5	12.7	12.2	13.8	15.4	16.3	15.1	15.1	16.2	16.3	15.7	14.0
FSTDEC	-10	2.3	2.2	2.1	2.4	2.7	2.8	2.6	2.6	2.8	2.8	2.7	2.4
FSTDEC	10	-2.6	-2.5	-2.4	-2.7	-2.9	-3.1	-2.8	-2.8	-3.0	-3.0	-2.9	-2.7
FSTDEC	50	-11.4	-10.9	-10.6	-11.7	-12.8	-13.3	-12.4	-12.4	-13.1	-13.1	-12.8	-11.8
MON-IFLW- CONC	-100	-0.3	-0.6	-0.4	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.0	-0.2	-0.2
MON-IFLW- CONC	-50	-0.2	-0.3	-0.2	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	-0.1	-0.1
MON-IFLW- CONC	50	0.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
MON-IFLW- CONC	100	0.3	0.6	0.4	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.1
MON-SQOLIM	-50	-8.9	-7.6	-4.4	-2.6	-3.8	-5.3	-4.7	-5.9	-4.3	-9.8	-16.3	-13.2
MON-SQOLIM	-25	-3.6	-2.9	-1.7	-1.0	-1.3	-2.0	-1.8	-2.4	-1.9	-4.4	-7.1	-5.5
MON-SQOLIM	50	11.2	6.0	2.7	1.6	2.2	2.9	2.5	3.3	2.8	7.8	17.8	17.1
MON-SQOLIM	100	19.6	11.2	4.6	2.6	3.5	4.6	3.9	4.9	4.2	11.4	24.1	26.7
WSQOP	-50	10.4	16.1	11.9	8.8	10.5	12.3	7.0	8.0	5.3	11.5	16.1	12.5
WSQOP	-10	1.4	2.2	1.7	1.2	1.4	1.7	1.0	1.1	0.7	1.5	2.1	1.7
WSQOP	10	-1.2	-1.9	-1.5	-1.1	-1.2	-1.5	-0.9	-1.0	-0.6	-1.3	-1.9	-1.5
WSQOP	50	-4.9	-7.9	-6.0	-4.2	-5.0	-6.2	-3.8	-3.8	-2.4	-5.3	-7.4	-5.9

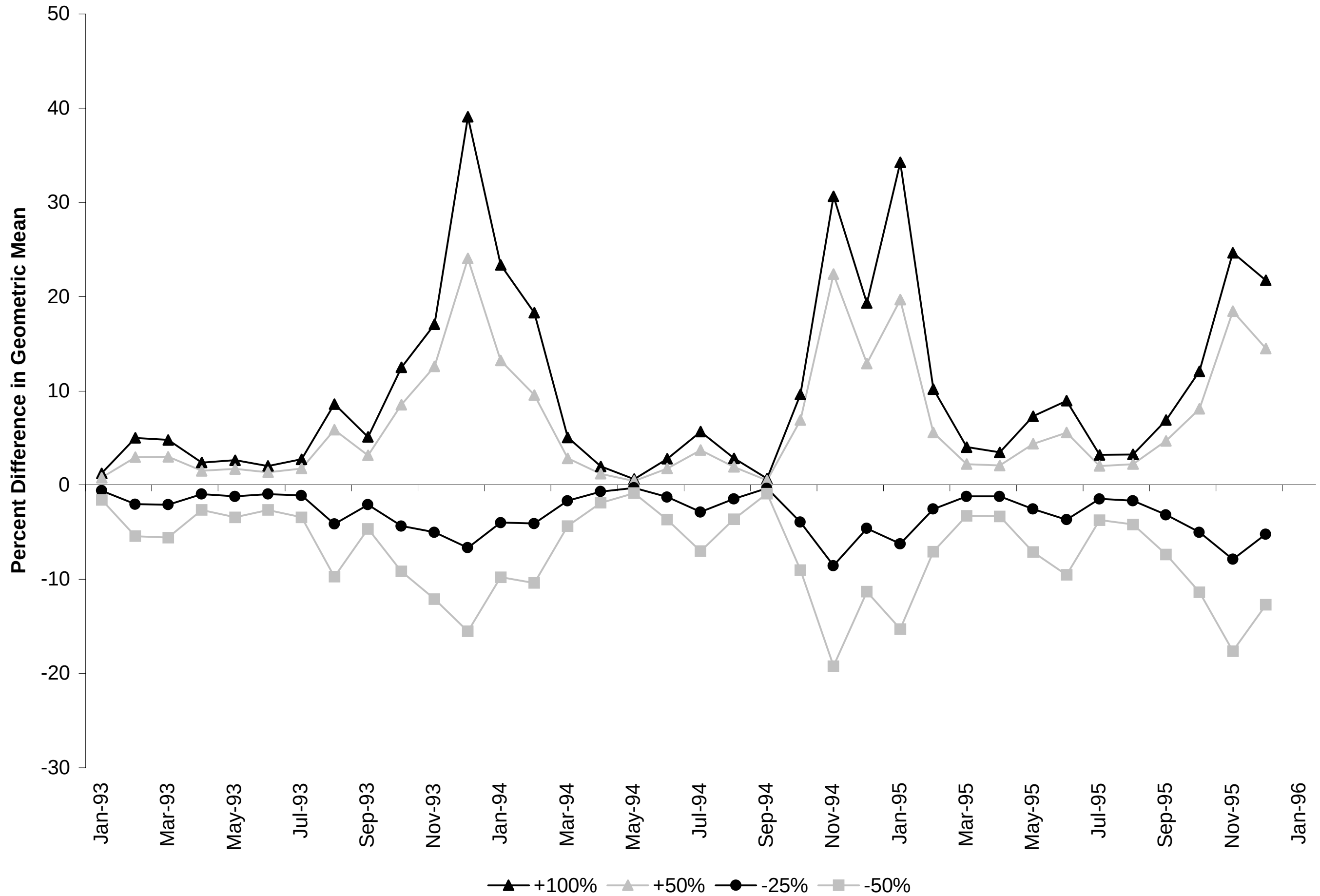

Figure 5.1 **Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in the maximum FC accumulation on land (MON-SQOLIM).**

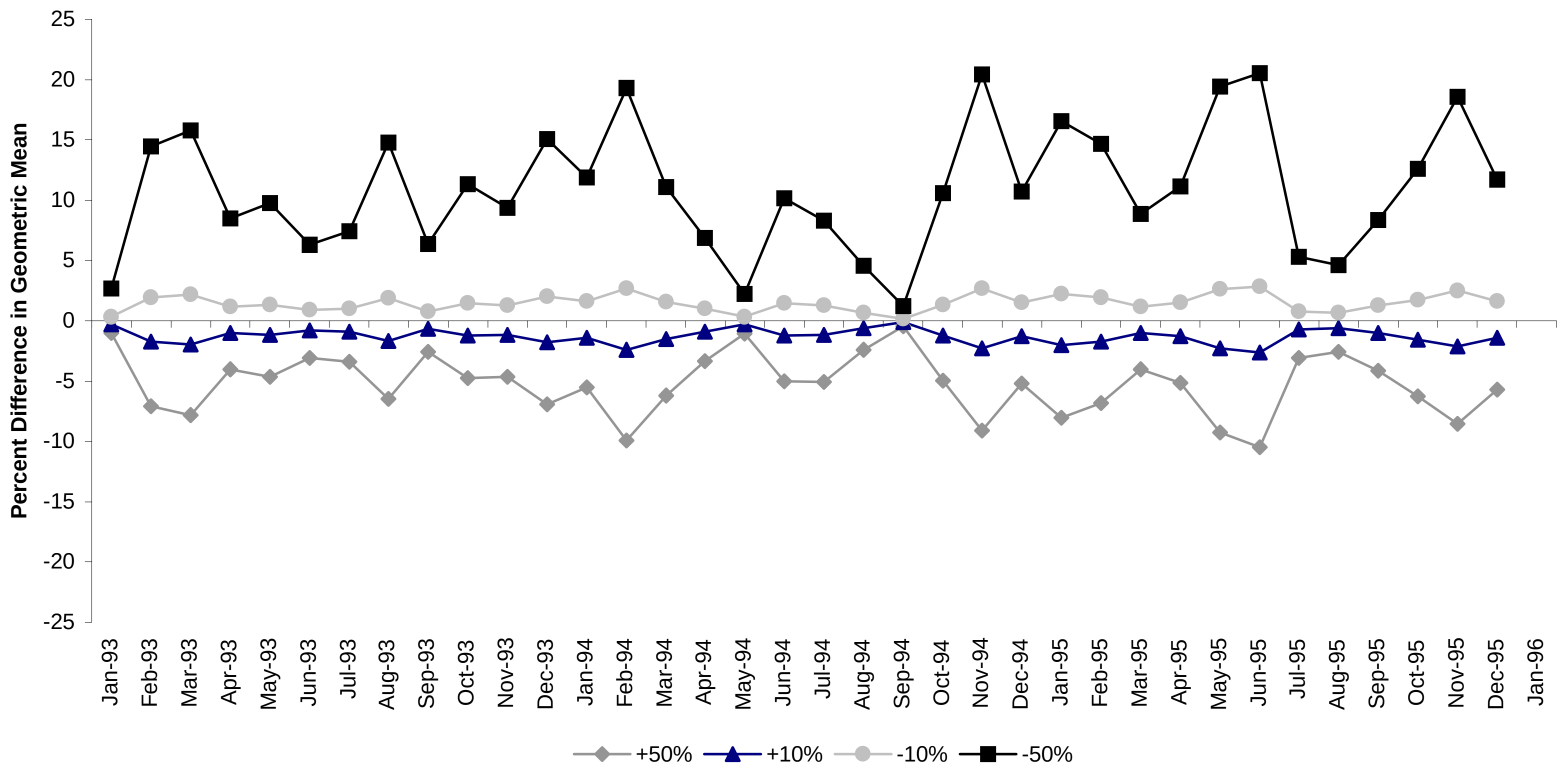

Figure 5.2 **Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in the rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP).**

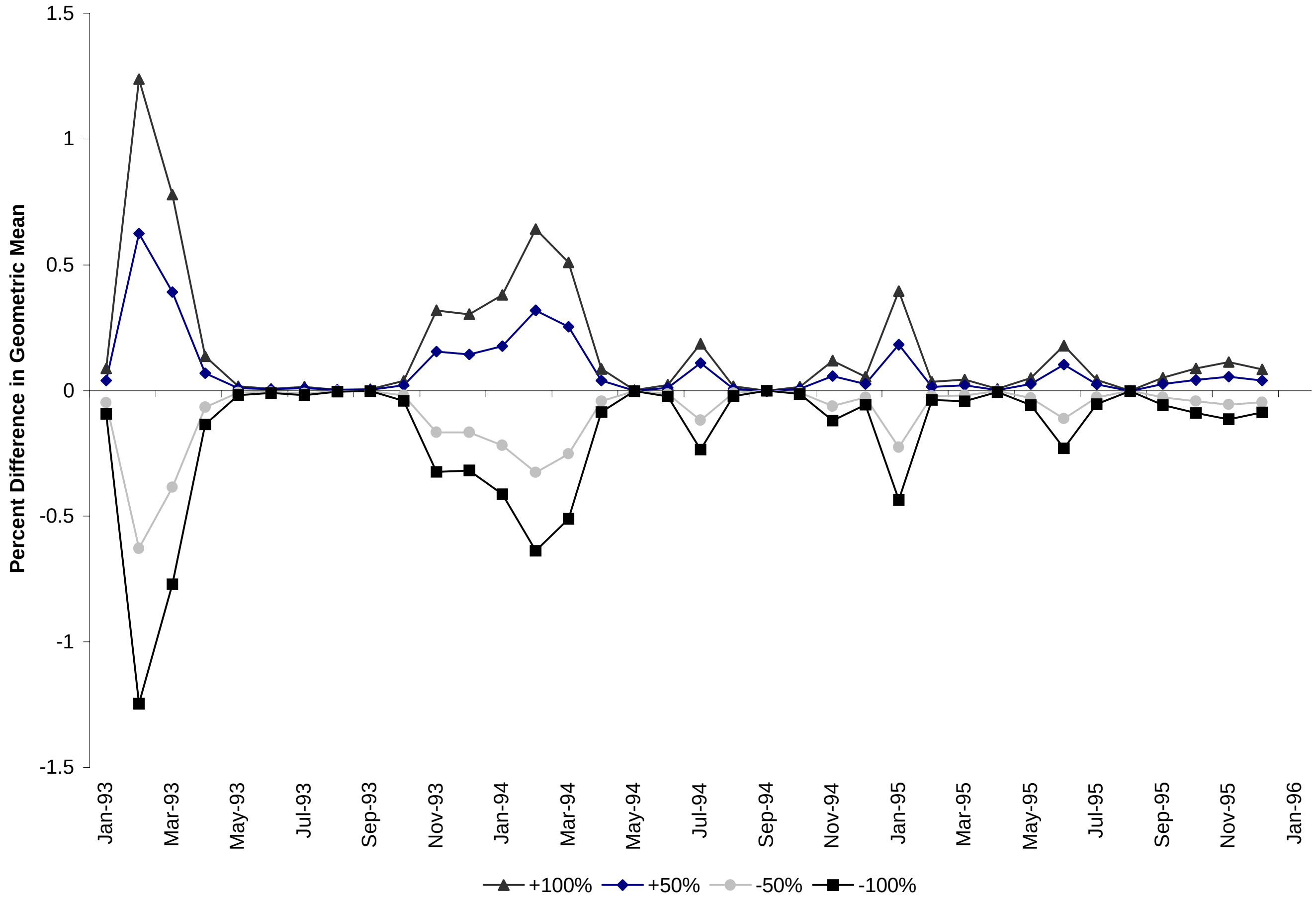

Figure 5.3 **Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in the concentration of fecal coliform in interflow (MON-IFLW-CONC).**

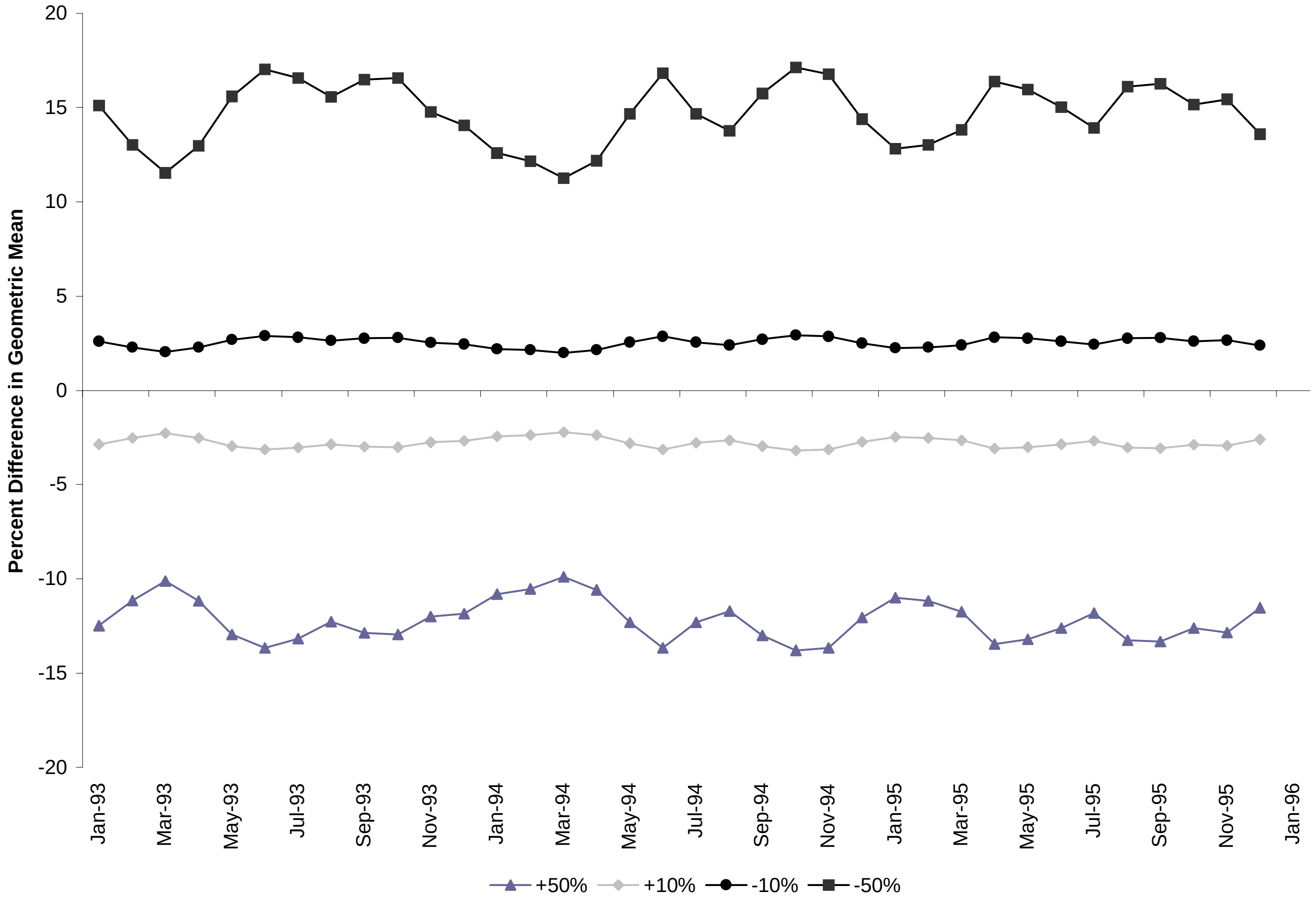

Figure 5.4 **Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

To describe the variability in source allocation, an initial base run was performed using precipitation data from 1992-1996 and model parameters established for 2001 conditions. Two sources of fecal coliform were considered in the sensitivity analyses; land-based loadings and direct deposition to the stream from nonpoint sources. Each of these sources was adjusted by four percentages (±10%, ±100%). The resulting percent change in total fecal coliform bacteria leaving the impairment area was recorded, and are presented in Figure 5.5.

Since the water quality standard for fecal coliform bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the 30-day geometric-mean fecal coliform concentration. A running 30-day geometric mean was calculated at each 15-minute time-step and the maximum value for each month was recorded. Deviations from the base run are plotted by month in Figures 5.6 and 5.7.

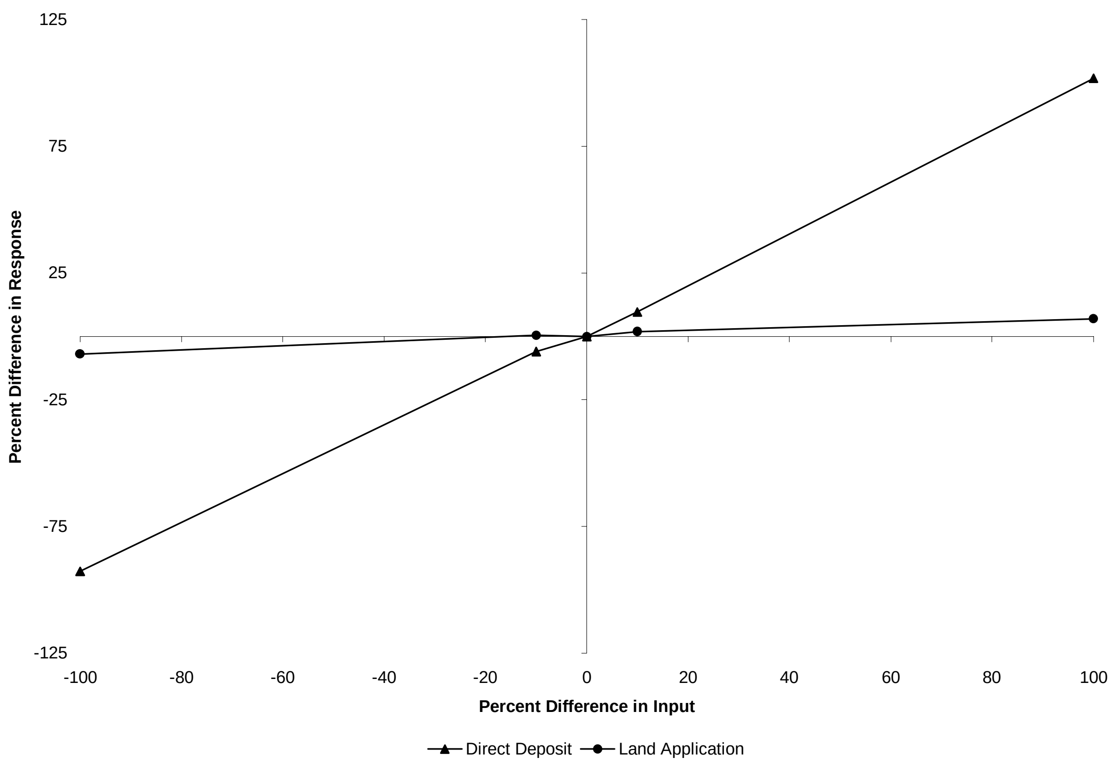

Figure 5.5 Results of total loading sensitivity analysis for the Gills Creek watershed.

Additionally, the effects of potential biosolids applications were analyzed. As was noted earlier (Section 3.2.3), 454 dry tons of RRWWTP biosolids, containing approximately 4.16×10^{10} cfu of fecal coliform and 474 dry tons of USRWWTP biosolids, containing approximately 2.95×10^{13} cfu of fecal coliform were applied in the Gills Creek drainage area during 1998. In 2000, 2,722 dry tons of RRWWTP biosolids, containing approximately 2.50×10^{11} cfu of fecal coliform were applied. Using the 1998 loadings, land-applied loadings would increase by 0.27%. This increase, based on average fecal coliform densities measured of 101 cfu/g and 68,467 cfu/g for RRWWTP and USRWWTP, respectively, would not have much effect on water quality as can be seen from Figure 5.6. If the full permitable fecal coliform density of 1,995,262 cfu/g was applied in 2000, the application would represent an increase of approximately 46%, and an increase in the maximum, 30-day, geometric mean of approximately 39% may be expected.

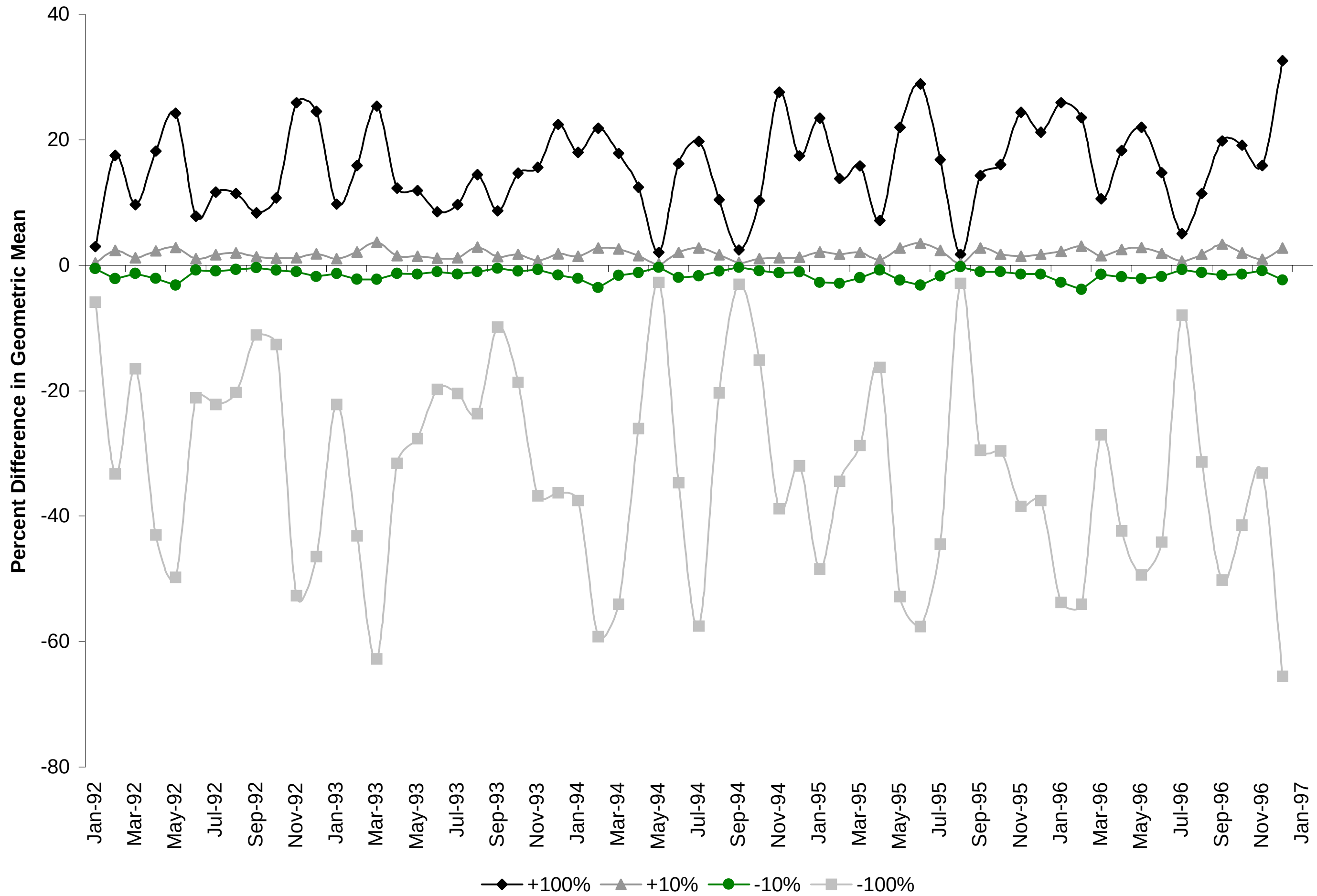

Figure 5.6 Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in land-based loadings.

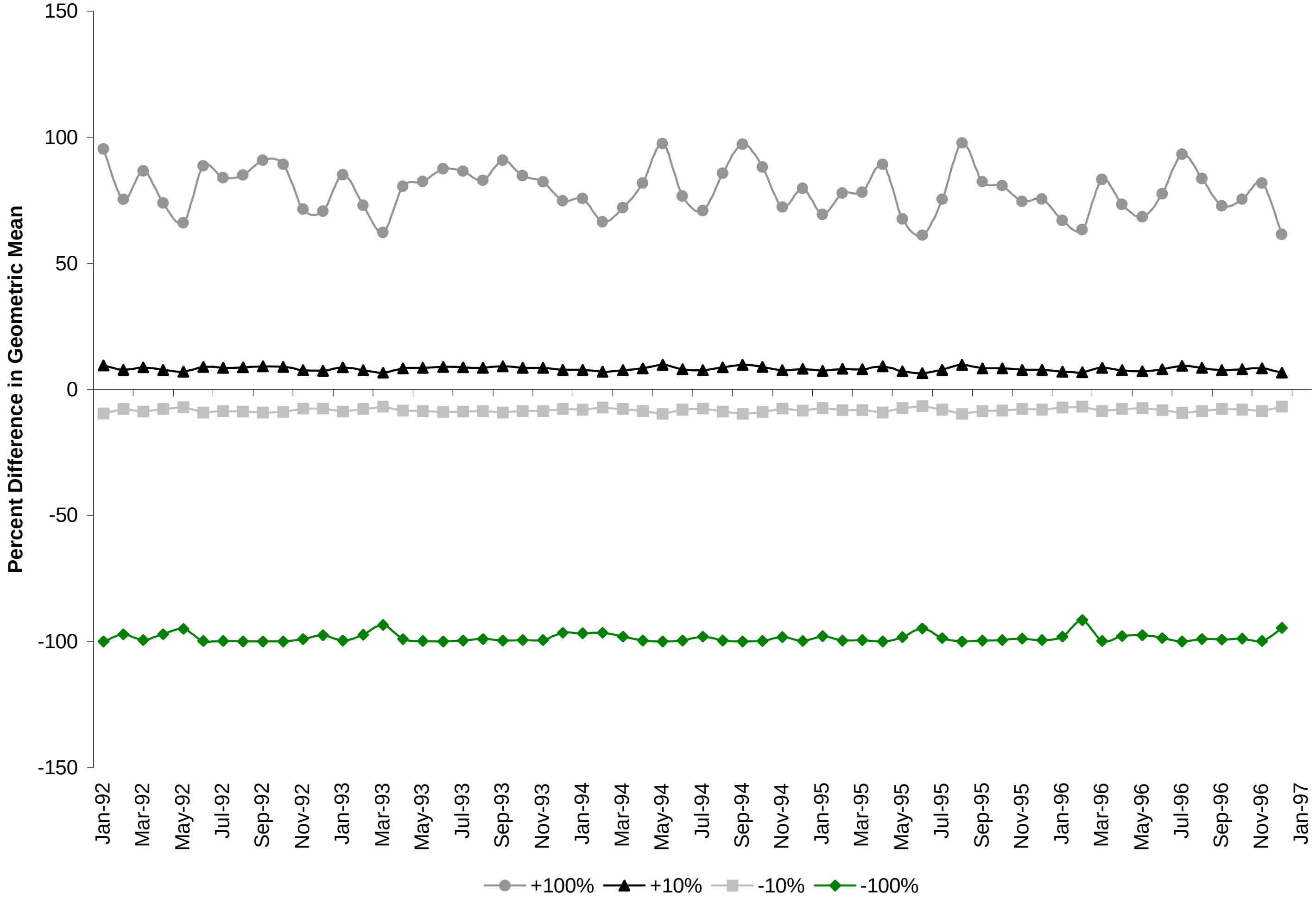

Figure 5.7 **Results of sensitivity analysis on 30-day geometric-mean concentrations in the Gills Creek watershed, as affected by changes in loadings from direct nonpoint sources.**

5.2 Incorporation of a Margin of Safety

A margin of safety (MOS) was incorporated into the TMDL in an effort to account for scientific errors inherent to the TMDL development process, measurement uncertainty in model parameters, and to account for trends which might prevent the water quality goal, as targeted by the TMDL, from being achieved. Scientific errors arise from our inability to fully describe mathematically the processes and mechanisms by which pollutants are delivered to the stream. Model calibration is an attempt to address these errors through adjusting model parameters until a suitable fit to observed data is achieved. Measurement uncertainty also introduces errors in the model calibration, because model parameters that are adjusted to non-representative conditions result in model simulations being biased either low or high. For example, observed data used for model calibration were collected for the purpose of detecting violations of the state's water quality standards. As a result, sample analyses are arbitrarily censored at a level above the state standard. This introduces modeling uncertainty during events that produce high pollutant concentrations. To ensure a pollutant reduction, long-term trends in pollutant sources must be considered in load allocations. For instance, if livestock populations within the targeted watershed are increasing, then a larger MOS might be appropriate to account for the expected increase in loads.

The MOS is a subjective value, representing a balance between complete certainty of reaching the in-stream standard and not meeting the standard. The MOS was entered explicitly as 5% of the maximum 30-day geometric mean standard (200 cfu/100ml). The result was that allocation scenarios were developed with the goal of maintaining the modeled 30-day geometric mean below 190 cfu/100ml.

5.3 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. The TMDL developed for the Gills Creek watershed was based on the Virginia State Standard for fecal coliform. As detailed in Section 1.2, the fecal coliform standard states that the 30-day geometric-mean concentration shall not exceed 200 cfu/100 ml. As such, pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard, reduced by a margin of safety equal to 5%, was met (Figure 5.8). The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

5.3.1 Wasteload Allocations

The Windy Gap Elementary School Wastewater Treatment Plant is the only permitted point source located within the Gills Creek impairment. School construction is slated for 2003-2004 concluding around August 2004. After which, discharge from facility will commence. This source has no limit on discharge but is designed to process 0.004 MGD. The impact on in-stream fecal coliform levels from this source was considered negligible. The allocation of the point source, Windy Gap Elementary School Wastewater Treatment Plant, is equivalent to its current permit levels (i.e. 0.004 MGD and 200 cfu/100ml).

5.3.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from land uses and direct applied loads in the stream (e.g. livestock, septic systems within 50 feet of a stream, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Within this framework, however, initial criteria that influenced developing load allocations included how sources were linked for representing existing conditions, and results from bacterial source tracking in the area. Direct deposition nonpoint sources were modeled with consistent loadings to the stream regardless of flow regime and had a significant impact on low flow concentrations. Bacterial source tracking during five 2001 sampling periods confirmed the presence of human, livestock and wildlife contamination.

With the impact of in-stream deposition very large, and the presence of human, livestock, and wildlife fecal material, an initial scenario was 100% reduction of uncontrolled residential discharges and 90% reduction in livestock stream access. All land-based allocations remained at existing conditions, that is, zero reduction.

This resulted in significant exceedances of the geometric mean standard (Table 5.5, Scenario 1). The exceedances all occurred in historically low flow periods (Table 2.4). With the exception of this period, all geometric means were less than the target of 190 cfu/100ml. A review of discharge data reveals that the discharge for the period is nearly equal to the twenty year low. These periods are nearly totally dominated by in-stream deposition limiting the scenarios to achieve the target to a reduction of livestock to 100% (i.e. total exclusion from streams), reduction of wildlife, and/or reduction of lateral flow from septic systems within 50 feet of streams. However, 100% reduction of livestock direct deposition did not meet the standard (Table 5.5, Scenario 2). Additional scenarios were explored incorporating a reduction in land-based loads (e.g. Table 5.5, Scenario 3) resulting in minimal reduction in the percent of exceedances.

As required by our contract, the TMDL allocations were to be developed using the State's 30-day geometric mean standard for fecal coliform. The geometric mean is designed to diminish the effect of a small number of extremely large observations, if the majority of observations are within acceptable limits. Because of this, it becomes important to understand the proportions of runoff events and low flow conditions within a 30-day window. Rudimentary analysis of 1994-1999 rainfall data indicate no more than seven percent of the time within any thirty day window was there a potential runoff event. Conversely, 93% of the time water quality was not directly impacted by surface runoff. So, the impact of the runoff events was relatively small, and the effect of reducing land-based loads was similarly small, as was observed in the TMDL analysis (Table 5.5, Scenario 3). As an example: assuming that runoff events impact in-stream concentrations 7% of the time (a conservative estimate for this watershed), if the geometric mean of fecal coliform concentrations during non-runoff event periods is 100 cfu/100 ml, then the geometric mean of fecal coliform concentrations during runoff events could be as much as four orders of magnitude greater and the state's water quality standard (30-day geometric mean < 200 cfu/100 ml) would still be met.

While Figure 5.6 shows that a significant reduction in the 30-day geometric mean concentration can be achieved through a reduction in the land-based sources during wet seasons, it is important to remember that the geometric mean is not an additive quantity. Therefore, a reduction in the land-based sources is not necessary in order to meet the standard. Since violations during the dry seasons were not influenced by the land-based sources, reductions in the direct deposition sources were necessary to reach the standard.

Additional scenarios were modeled to achieve the target through the reduction of direct deposition, the dominant impacting source for these low flow conditions. A scenario including lateral flow from septic systems within 50 feet of streams had a minor impact on the geometric mean for the low flow period (Table 5.5, Scenario 4). A scenario removing all sources except wildlife direct deposition resulted in continued exceedances in fall 1993, a period of particularly low flows (Table 5.5, Scenario 5).

Several model runs were made investigating scenarios that involved the reduction of wildlife required to meet the standard for the low flow condition (Table 5.5, Scenarios 6-8). The final scenario involved a 95% reduction (Table 5.5, Scenario 8; Figure 5.8). In meeting the standard during the dry seasons, reductions were sufficient so as not to require a reduction in land-based sources during the wet seasons. The load allocation becomes no reduction of land applied fecal material, no reduction of septic systems within 50 feet of streams since the impact was negligible, 100% reduction of livestock in-stream deposition, 100% reduction of uncontrolled residential discharges, and 95% reduction of wildlife in-stream deposition (Tables 5.6 and 5.7). Although there is no reduction of land applied fecal material, implicit in allocation is a need to maintain loadings at or below the current levels.

Table 5.5 Percentage of 30-day geometric mean values exceeding 190 cfu/100 ml fecal coliform in the Gills Creek impairment.

Scenario Number	Percent Reduction in Loading from Existing Condition					Percentage of Days with 30-day GM>190 cfu/100ml
	Direct Wildlife Deposits	Direct Cattle Deposits	NPS from Land Segments	Direct Straight Pipes	Direct Septic Lateral Flow	
1	0	90	0	100	0	31.20
2	0	100	0	100	0	11.59
3	0	100	50	100	0	7.71
4	0	100	0	100	100	11.59
5	0	100	100	100	100	2.94
6	75	100	0	100	0	1.53
7	90	100	0	100	0	0.56
8	95	100	0	100	0	0.00

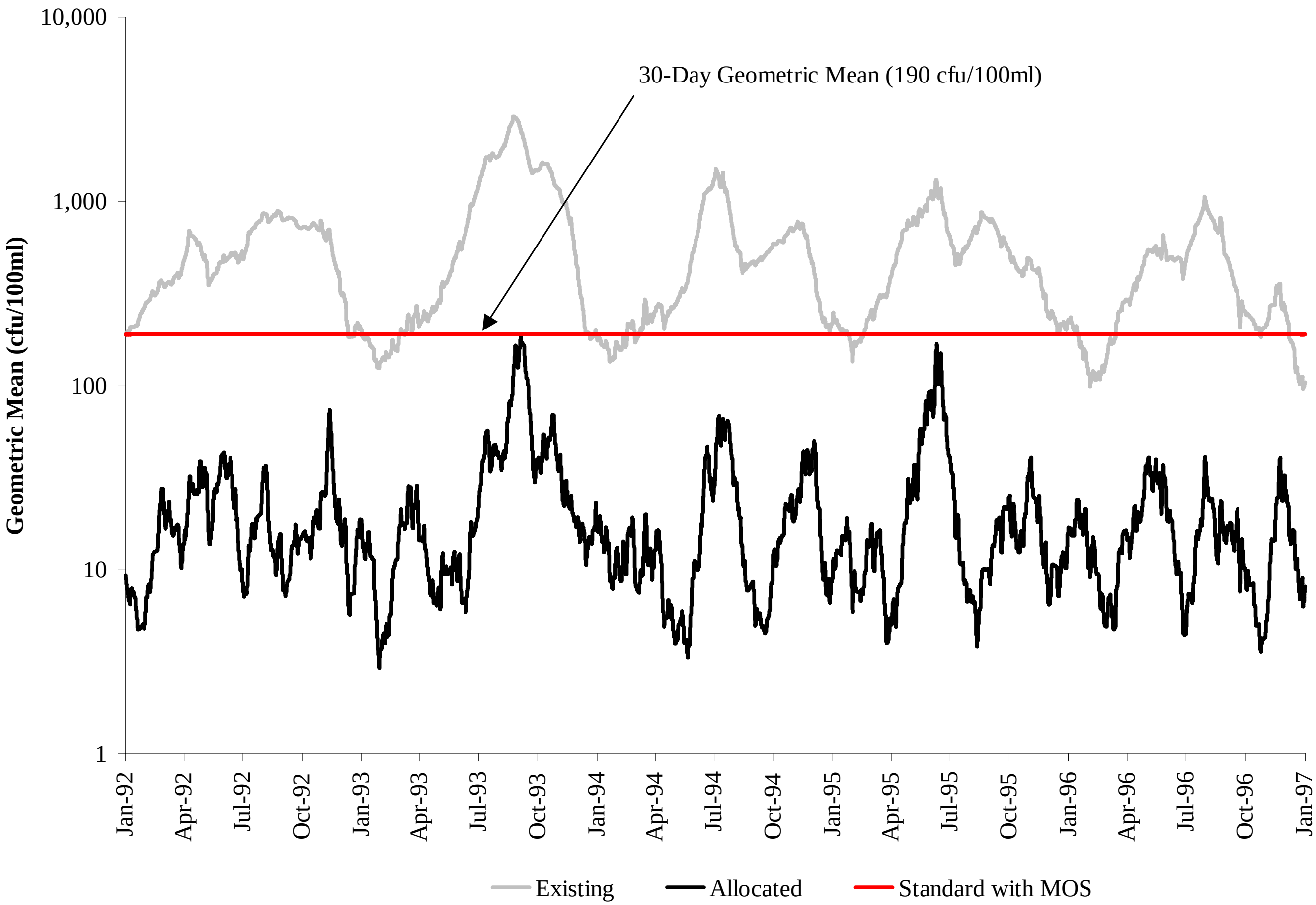

Figure 5.8 Allocation and existing scenarios for Gills Creek impairment.

Table 5.6 Land-based nonpoint source load reductions in the Gills Creek impairment for final allocation.

Land use	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Good Pasture	1.37E+15	1.37E+15	0
Poor Pasture	1.49E+15	1.49E+15	0
Cropland	6.18E+15	6.18E+15	0
Forest	6.02E+14	6.02E+14	0
Urban	3.24E+14	3.24E+14	0
Farmstead	1.18E+13	1.18E+13	0
Livestock Access	5.42E+13	1.69E+14	-211
Loafing Lot	4.48E+14	4.48E+14	0
Golf Course	1.14E+12	1.14E+12	0
Hay / Grass	1.24E+14	1.24E+14	0

Table 5.7 Load reductions to direct nonpoint sources in the Gills Creek impairment for final allocation.

Subw'shed	Wildlife (cfu/year)			Straight Pipes (cfu/year)		
	Existing Load	Allocated Load	% Red.	Existing Load	Allocated Load	% Red.
1	2.15E+11	1.07E+10	95	7.58E+10	0.00E+00	100
2	8.82E+11	4.41E+10	95	2.91E+10	0.00E+00	100
3	6.37E+11	3.18E+10	95	6.25E+10	0.00E+00	100
4	2.48E+12	1.24E+11	95	5.15E+10	0.00E+00	100
5	2.20E+12	1.10E+11	95	8.66E+10	0.00E+00	100
6	5.29E+12	2.64E+11	95	5.50E+10	0.00E+00	100
7	3.04E+12	1.52E+11	95	2.84E+10	0.00E+00	100
8	3.10E+12	1.55E+11	95	4.08E+10	0.00E+00	100
9	3.34E+12	1.67E+11	95	4.26E+10	0.00E+00	100
TOTAL	2.12E+13	1.06E+12	95	4.72E+11	0.00E+00	100

Subw'shed	Lateral Flow (cfu/year)			Livestock (cfu/year)		
	Existing Load	Allocated Load	% Red.	Existing Load	Allocated Load	% Red.
1	1.70E+08	1.70E+08	0	4.66E+12	0.00E+00	100
2	5.44E+07	5.44E+07	0	2.04E+12	0.00E+00	100
3	5.78E+07	5.78E+07	0	9.16E+12	0.00E+00	100
4	2.70E+07	2.70E+07	0	4.40E+13	0.00E+00	100
5	0.00E+00	0.00E+00	--	6.66E+12	0.00E+00	100
6	2.67E+07	2.67E+07	0	4.17E+13	0.00E+00	100
7	0.00E+00	0.00E+00	--	2.42E+12	0.00E+00	100
8	4.94E+08	4.94E+08	0	1.86E+12	0.00E+00	100
9	4.73E+08	4.73E+08	0	2.02E+12	0.00E+00	100
TOTAL	1.30E+09	1.30E+09	0	1.14E+14	0.00E+00	100

Table 5.8 represents the average annual loads during the modeled period after allocation of pollutant loads. Loads from permitted point sources (WLA) and nonpoint sources (LA) are represented, as are the load associated with the margin of safety (MOS) and the sum of these three loads (TMDL). It is worth noting that the MOS is much less than 5% of the TMDL. This outcome illustrates the inherent difference between concentration, which is the amount of a pollutant (e.g. numbers of fecal coliforms) in a given volume of water, and annual loads, which is the total amount of the pollutant regardless of the volume of water. Additionally, this situation reflects the fact that it would be inappropriate to use annual loads, such as those in Table 5.7, as a target goal for meeting a water quality standard that is based on concentrations.

Table 5.8 Average annual loads (cfu/year) modeled after TMDL allocation in the Gills Creek watershed.

Impairment	WLA[1]	LA	MOS	TMDL
Total	1.10E+10	1.99E+14	6.48+12	1.99E+14

1 The only point source permitted for fecal control in the Gills Creek drainage is Windy Gap Elementary School WWTP (VPDES # VA0090719). A design flow of 0.004 MGD at a fecal coliform concentration of 200 cfu/100 ml results in a WLA of 1.10E+10 cfu/year.

The practical implications of a required reduction in wildlife direct deposition would suggest that some alternative water quality target may be in order, as implied by the state's legislative language regarding naturally occurring and low-flow conditions (Section 1.2). However, the purpose of the TMDL development process is to assess all sources contributing to the impairment. It is this assessment that identifies these naturally occurring and/or low flow conditions and thereby can serve as a means of triggering the legislative response (i.e. removal of a designated use, Virginia State Law Section 9VAC25-260-10, Subsection G).

Future growth was estimated and projected to the year 2006. Population growth was based on 19.6% increase for the period from 1990 through 2000 (USCB, 2000). Dairy numbers were found to be decreasing at the rate of 5.91% per year with beef numbers decreasing at the rate of 6.20% per year (VASS,1998; VASS, 1999; MapTech, 1999). For the year 2006 projection, the percent difference in land-based and directly deposited waste was calculated. Because the TMDL specifies 100% exclusion of livestock from streams and 100% elimination of straight pipes, direct load allocations for this projection are based solely on an increase in lateral flow from septic systems within 50 ft of a stream. This increase in direct loads is negligible (i.e. <0.0001% increase). With decreasing trends in livestock, projected land-based waste load on agricultural land uses was assumed to at least equal current loads. Increases in land-based waste on the urban land use were projected to increase by a maximum of 10.9%. Based on the sensitivity analysis, a 10% land-based load increase on all land uses would produce a maximum geometric mean increase of 3.6% (Figure 5.6). Figure 5.7 shows that, during wet periods, a 3.6% increase in the geometric mean could be tolerated without violating the standard.

6. IMPLEMENTATION

6.1 Reasonable Assurance for Implementation

6.1.1 Follow-Up Monitoring

The Virginia Department of Environmental Quality will continue to monitor Gills Creek in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

6.1.2 Regulatory Framework

The goal of this TMDL is to establish a three-step path that will lead to expeditious attainment of water quality standards. The first step in this process was to develop load reductions for sources of fecal coliform bacteria to Gills Creek using a watershed model, and is the purpose of this report. The second step is to develop a TMDL implementation plan, and the final step is to implement the TMDL and attain water quality standards.

Section 303(d) of the Clean Water Act (CWA) and current USEPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring Information and Restoration Act (WQ MIRA) directs VADEQ in section 62.1-44.197.7 to "develop and implement a plan to achieve fully supporting status for impaired waters". The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated cost, benefits and environmental impact of addressing the impairments. USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan and milestones for attaining water quality standards.

Since this TMDL consists primarily of NPS load allocations, VADCR will have the lead for the development of the implementation plan. Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of VADEQ, VADCR, VDH and other cooperating agencies.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the Roanoke River Water Quality Management Plan, in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to USEPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

6.1.3 Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA Conservation Reserve Enhancement Program, the USDA Environmental Quality Incentives Program, the state revolving loan programs, and the VA Water Quality Improvement Fund.

6.2 Implementation Plan

The Commonwealth intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementations are: 1) as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved; 2) it provides a measure of quality control, given the uncertainties which exist in any model; 3) it provides a mechanism for developing public support; 4) it helps to ensure the most cost effective practices are implemented initially; and 5) it allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard.

While specific stage I goals for BMP implementation will be established as part of the implementation plan development process, some general guidelines and suggestions are outlined below.

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, the most promising management practice in agricultural areas of the watershed is livestock exclusion from streams. This has been shown to be very effective in lowering fecal coliform concentrations in streams, both from the cattle deposits themselves and from additional buffering in the riparian zone. Additionally, reducing the human bacteria loading from failing septic systems and straight pipes should be a focus during the first stage because of its health implications. This component could be implemented through education on septic pump-outs as well as a sanitary sewer inspection and management program.

The stage I water quality goal was to reduce the number of violations of the instantaneous standard to less than 10%. The stage I allocation developed for Gills Creek requires a 100% reduction of uncontrolled residential discharges and a 90% reduction in livestock direct deposition to the stream (Tables 6.1 and 6.2).

Public participation during the implementation plan development process will include the formation of stakeholders committee and open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders committee will have the expressed purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from the VADEQ, VADCR, VDH, local agricultural community, local urban community, local governments, and independent technical advisors. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to insure expeditious implementation and set measurable goals and milestones for attaining water quality standards.

The development of the implementation plan is expected to be an iterative process, with monitoring data refining its final design. Subsequent refinements will be made as the progress toward meeting milestones and the expressed TMDL goals is assessed. As practices are implemented, periodic analyses of water quality conditions will be conducted to evaluate the progress toward meeting end goals. Implementation of control measures will begin after the implementation plan development is completed, which is expected to cover a timeline of approximately seven months.

Table 6.1 Nonpoint source allocations in the Gills Creek impairment for Stage I implementation.

Land use	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Good Pasture	1.37E+15	1.37E+15	0
Poor Pasture	1.49E+15	1.49E+15	0
Cropland	6.18E+15	6.18E+15	0
Forest	6.02E+14	6.02E+14	0
Urban	3.24E+14	3.24E+14	0
Farmstead	1.18E+13	1.18E+13	0
Livestock Access	5.42E+13	1.57E+14	-189
Loafing Lot	4.48E+14	4.48E+14	0
Golf Course	1.14E+12	1.14E+12	0
Hay / Grass	1.24E+14	1.24E+14	0

Table 6.2 Load reductions to direct nonpoint sources in the Gills Creek impairment for Stage I implementation.

Subw'shed	Wildlife (cfu/year)			Straight Pipes (cfu/year)		
	Existing Load	Allocated Load	% Red.	Existing Load	Allocated Load	% Red.
1	2.15E+11	2.15E+11	0	7.58E+10	0.00E+00	100
2	8.82E+11	8.82E+11	0	2.91E+10	0.00E+00	100
3	6.37E+11	6.37E+11	0	6.25E+10	0.00E+00	100
4	2.48E+12	2.48E+12	0	5.15E+10	0.00E+00	100
5	2.20E+12	2.20E+12	0	8.66E+10	0.00E+00	100
6	5.29E+12	5.29E+12	0	5.50E+10	0.00E+00	100
7	3.04E+12	3.04E+12	0	2.84E+10	0.00E+00	100
8	3.10E+12	3.10E+12	0	4.08E+10	0.00E+00	100
9	3.34E+12	3.34E+12	0	4.26E+10	0.00E+00	100
TOTAL	2.12E+13	2.12E+13	0	4.72E+11	0.00E+00	100

Subw'shed	Lateral Flow (cfu/year)			Livestock (cfu/year)		
	Existing Load	Allocated Load	% Red.	Existing Load	Allocated Load	% Red.
1	1.70E+08	1.70E+08	0	4.66E+12	4.66E+11	90
2	5.44E+07	5.44E+07	0	2.04E+12	2.04E+11	90
3	5.78E+07	5.78E+07	0	9.16E+12	9.16E+11	90
4	2.70E+07	2.70E+07	0	4.40E+13	4.40E+12	90
5	0.00E+00	0.00E+00	--	6.66E+12	6.66E+11	90
6	2.67E+07	2.67E+07	0	4.17E+13	4.17E+12	90
7	0.00E+00	0.00E+00	--	2.42E+12	2.42E+11	90
8	4.94E+08	4.94E+08	0	1.86E+12	1.86E+11	90
9	4.73E+08	4.73E+08	0	2.02E+12	2.02E+11	90
TOTAL	1.30E+09	1.30E+09	0	1.14E+14	1.14E+13	90

6.3 Public Participation

The development of the Gills Creek TMDL would not have been possible without public participation. During the course of developing the TMDL for Gills Creek, three meetings were held (Table 6.3). One meeting was open to agency personnel and two were public meetings. The agency meeting was convened on October 2, 2001 at the Blue Ridge Soil and Water Conservation office in Rocky Mount, 8 people attended. Members were invited to participate in discussions outlining the development process and subsequent meetings.

The first public meeting on December 6, 2001 was held in Burnt Chimney, 60 people attended. The meeting was public noticed in the *Virginia Register* and *Franklin News*

Post. Additionally, public announcements were made on the local cable television network and letters were sent to watershed residents inviting them to the meetings. A basic description of the TMDL process, agencies involved, details of the hydrologic calibration, and pollutant sources were presented at the first public meeting. Copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received.

The second public meeting was held in Moneta on March 18, 2002, 25 people attended. The meeting was public noticed in the *Virginia Register* and *Franklin News Post*. Public announcements were also made on the local cable television network and letters were sent to watershed residents inviting them to the meetings. The final model simulations and the TMDL load allocations were presented during this meeting. Copies of the presentation materials and the draft TMDL were available for public distribution. There was a 30 day-public comment period and three comment letters were received.

During the second public meeting, it was explained why spatial data from the 1990 Census was used in the source assessment and load development. Considerable time and resources were spent searching for detailed 2000 Census spatial data during load development. Despite the efforts by MapTech, it was concluded that spatial data from the 2000 Census were not obtainable. At the same meeting, the Assistant County Administrator addressed concern that 1990 census data was used to develop FC loads. The suggestion was made that 2000 census data was available from Franklin County, and referred MapTech to the West Piedmont Planning District Commission in order to obtain this data (Newlon, 2002). After following up with the planning district, it was again concluded that detailed census data beyond 1990 was not available for utilization in the source load development (Manning, 2002).

Table 6.3 Public participation in the TMDL development for the Gills Creek watershed.

Date[1]	Location	Attendance[1]	Format
10/2/01	BRSWCD Office; Rocky Mount, VA	8 project personnel	Agency personnel by invitation
12/6/01	Burnt Chimney Elementary School; Burnt Chimney, VA	54 watershed residents, 6 project personnel	Open to public at large
3/18/02	Fellowship Hall of Trinity Ecumenical Parish; Moneta, VA	18 watershed residents, 7 project personnel	Open to public at large

[1] The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to under estimate the actual attendance.

APPENDIX: A

FECAL COLIFORM DISTRIBUTIONS FOR EACH SAMPLING STATION IN GILLS CREEK

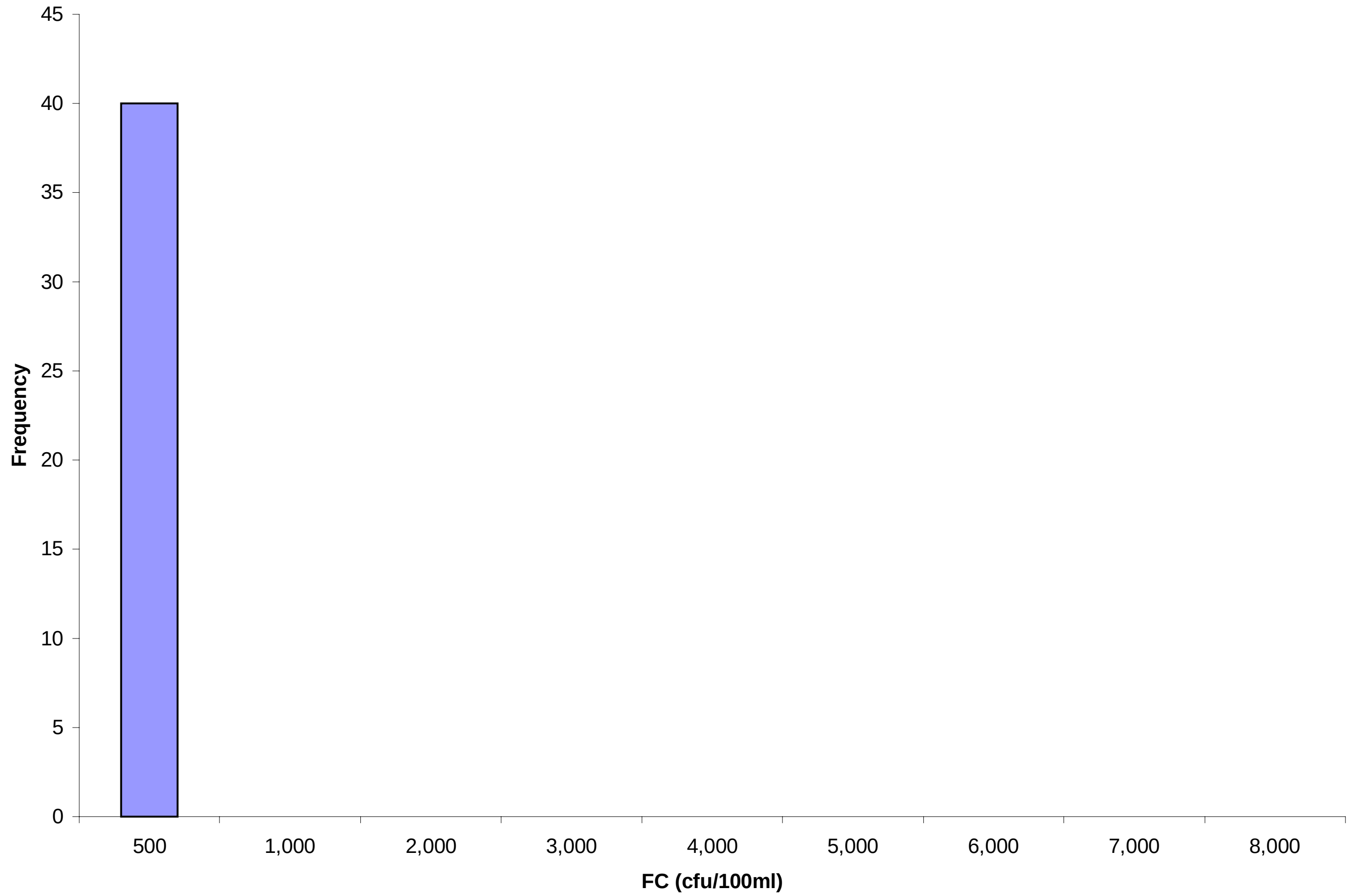

Figure A.1 Frequency analysis of fecal coliform concentrations at station 4GIL002.39 in the Gills Creek impairment for period June 1990 to August 2001.

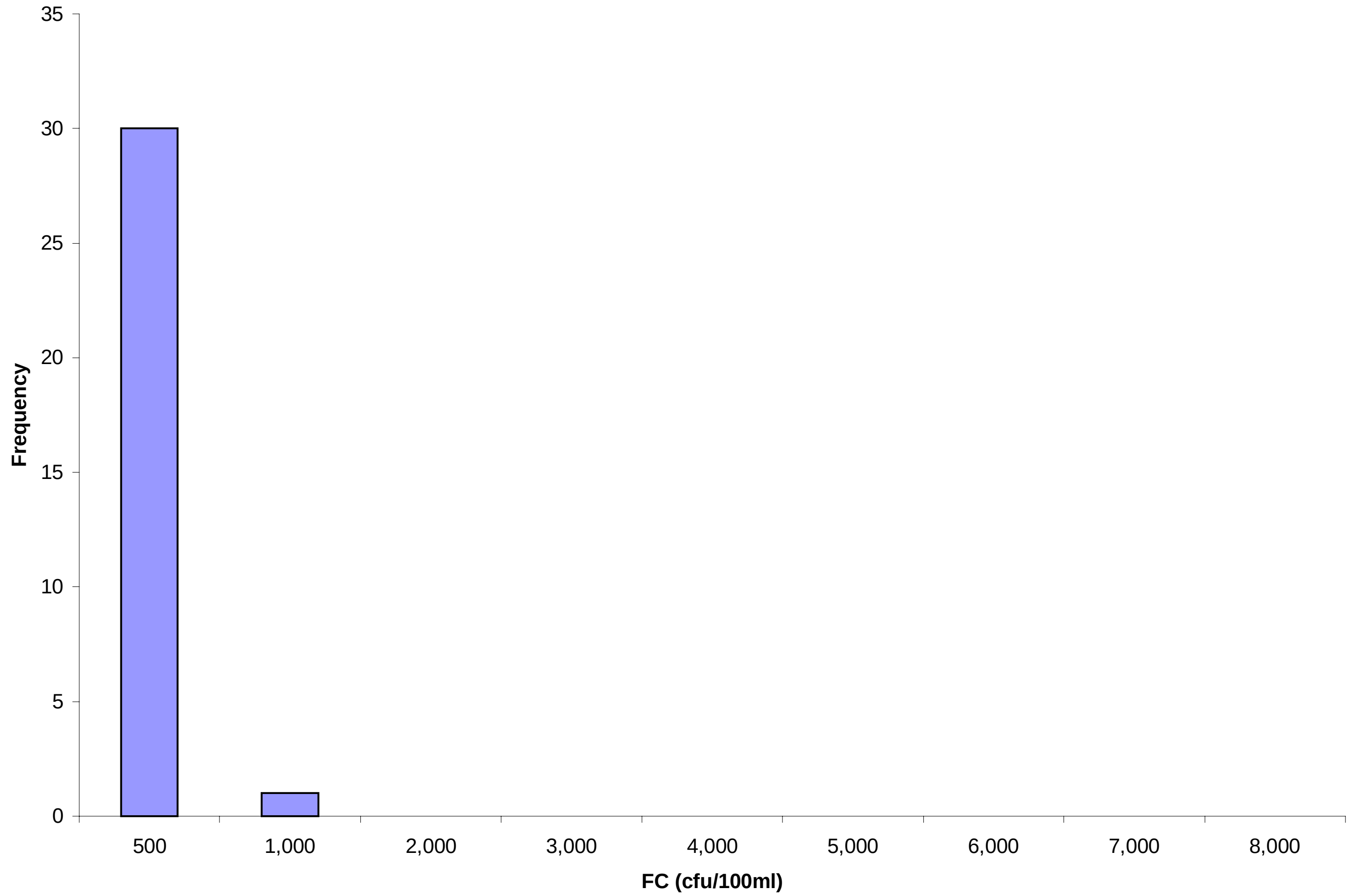

Figure A.2 Frequency analysis of fecal coliform concentrations at station 4AGIL004.46 in the Gills Creek impairment for period July 1971 to June 1976 and August 2001.

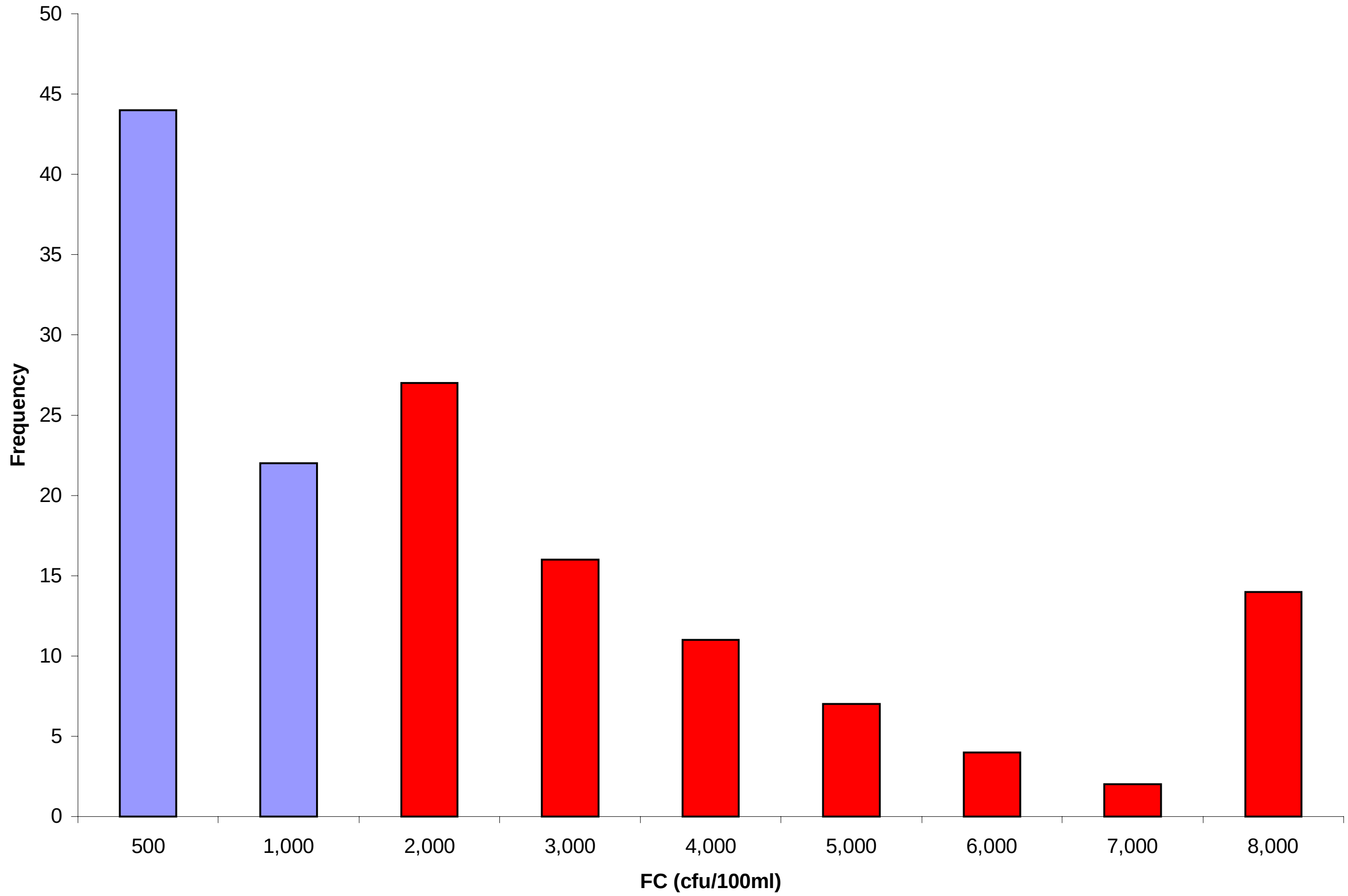

Figure A.3 Frequency analysis of fecal coliform concentrations at station 4AGIL008.30 in the Gills Creek impairment for period May 1991 to August 2001.

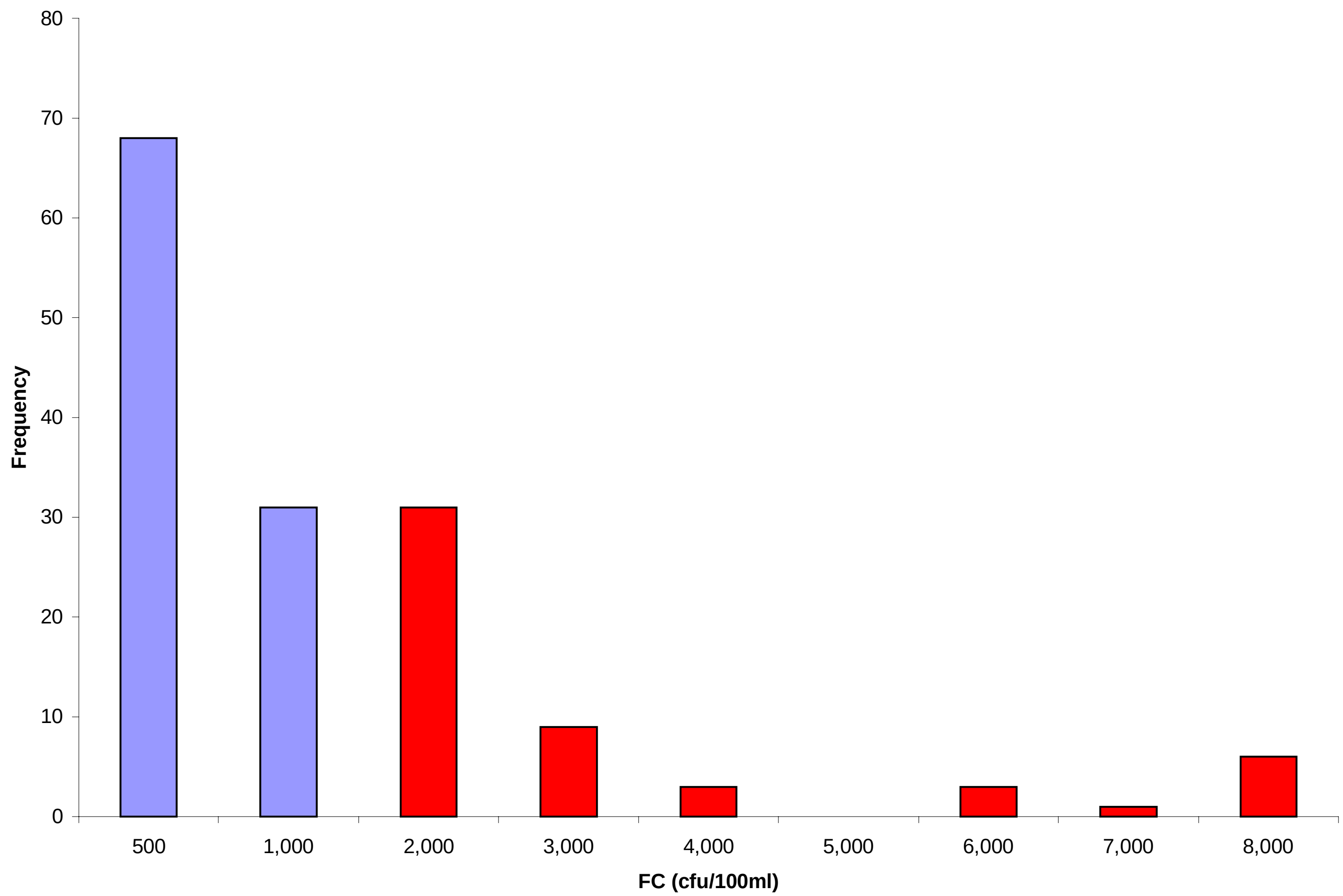

Figure A.4 Frequency analysis of fecal coliform concentrations at station 4AGIL023.22 in the Gills Creek impairment for period May 1991 to August 2001.

APPENDIX: B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions (2001) of land applied fecal coliform load for Gills Creek impairment.

Date	Good Pasture (cfu/ac*day)	Poor Pasture (cfu/ac*day)	Cropland (cfu/ac*day)	Forest (cfu/ac*day)	Urban (cfu/ac*day)
January	1.27E+10	1.88E+10	1.23E+10	1.05E+09	3.28E+09
February	1.42E+10	1.96E+10	1.41E+10	1.05E+09	3.28E+09
March	1.40E+10	1.95E+10	1.27E+11	1.05E+09	3.27E+09
April	1.39E+10	1.95E+10	1.27E+11	1.04E+09	3.27E+09
May	1.40E+10	1.98E+10	1.27E+11	1.04E+09	3.27E+09
June	1.81E+10	3.38E+10	1.23E+09	1.04E+09	3.26E+09
July	1.81E+10	3.39E+10	1.24E+09	1.03E+09	3.26E+09
August	1.81E+10	3.39E+10	1.24E+09	1.03E+09	3.26E+09
September	1.41E+10	2.01E+10	3.81E+10	1.03E+09	3.26E+09
October	1.43E+10	2.04E+10	1.27E+11	1.03E+09	3.25E+09
November	1.28E+10	1.94E+10	1.27E+11	1.03E+09	3.26E+09
December	1.29E+10	1.94E+10	1.23E+10	1.05E+09	3.27E+09

Table B.1 Current conditions (2001) of land applied fecal coliform load for Gills Creek impairment. (Continued)

Date	Farmstead (cfu/ac*day)	Livestock Access (cfu/ac*day)	Loafing Lot (cfu/ac*day)	Golf Course (cfu/ac*day)	Hay/Grass (cfu/ac*day)
January	2.76E+09	2.46E+09	1.12E+11	3.28E+08	1.12E+09
February	2.75E+09	2.69E+09	1.12E+11	3.28E+08	1.12E+09
March	2.75E+09	4.23E+09	1.08E+11	3.28E+08	1.12E+09
April	2.75E+09	5.76E+09	1.02E+11	3.28E+08	1.12E+09
May	2.74E+09	5.75E+09	9.97E+10	3.28E+08	1.12E+09
June	2.74E+09	7.27E+09	9.79E+10	3.28E+08	1.12E+09
July	2.73E+09	7.31E+09	9.58E+10	3.28E+08	1.12E+09
August	2.73E+09	7.31E+09	9.58E+10	3.28E+08	1.12E+09
September	2.73E+09	5.77E+09	9.58E+10	3.28E+08	1.12E+09
October	2.73E+09	4.23E+09	9.70E+10	3.28E+08	1.12E+09
November	2.73E+09	3.91E+09	9.97E+10	3.28E+08	1.12E+09
December	2.75E+09	2.47E+09	1.05E+11	3.28E+08	1.12E+09

Table B.2 Monthly, directly-deposited, fecal coliform loads in the Gills Creek impairment.

Reach	Source	Jan (cfu/day)	Feb (cfu/day)	Mar (cfu/day)	Apr (cfu/day)	May (cfu/day)	Jun (cfu/day)
1	Wildlife	5.89E+08	5.89E+08	5.89E+08	5.88E+08	5.88E+08	5.88E+08
	Human	2.08E+08	2.08E+08	2.08E+08	2.08E+08	2.08E+08	2.08E+08
	Livestock	6.08E+09	7.51E+09	1.13E+10	1.50E+10	1.50E+10	1.88E+10
2	Wildlife	2.42E+09	2.42E+09	2.42E+09	2.42E+09	2.42E+09	2.42E+09
	Human	7.98E+07	7.98E+07	7.98E+07	7.98E+07	7.98E+07	7.98E+07
	Livestock	2.66E+09	3.30E+09	4.95E+09	6.60E+09	6.60E+09	8.24E+09
3	Wildlife	1.75E+09	1.75E+09	1.75E+09	1.75E+09	1.75E+09	1.75E+09
	Human	1.71E+08	1.71E+08	1.71E+08	1.71E+08	1.71E+08	1.71E+08
	Livestock	1.05E+10	1.13E+10	2.06E+10	2.99E+10	2.99E+10	3.92E+10
4	Wildlife	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09
	Human	1.41E+08	1.41E+08	1.41E+08	1.41E+08	1.41E+08	1.41E+08
	Livestock	4.82E+10	4.89E+10	9.65E+10	1.44E+11	1.44E+11	1.91E+11
5	Wildlife	6.03E+09	6.03E+09	6.03E+09	6.03E+09	6.03E+09	6.03E+09
	Human	2.37E+08	2.37E+08	2.37E+08	2.37E+08	2.37E+08	2.37E+08
	Livestock	8.79E+09	1.07E+10	1.61E+10	2.14E+10	2.14E+10	2.68E+10
6	Wildlife	1.45E+10	1.45E+10	1.45E+10	1.45E+10	1.45E+10	1.45E+10
	Human	1.51E+08	1.51E+08	1.51E+08	1.51E+08	1.51E+08	1.51E+08
	Livestock	4.69E+10	4.87E+10	9.25E+10	1.36E+11	1.36E+11	1.80E+11
7	Wildlife	8.32E+09	8.32E+09	8.32E+09	8.32E+09	8.32E+09	8.32E+09
	Human	7.77E+07	7.77E+07	7.77E+07	7.77E+07	7.77E+07	7.77E+07
	Livestock	3.08E+09	4.08E+09	5.97E+09	7.80E+09	7.50E+09	8.88E+09
8	Wildlife	8.49E+09	8.49E+09	8.49E+09	8.48E+09	8.48E+09	8.48E+09
	Human	1.13E+08	1.13E+08	1.13E+08	1.13E+08	1.13E+08	1.13E+08
	Livestock	2.42E+09	3.00E+09	4.50E+09	6.00E+09	6.00E+09	7.50E+09
9	Wildlife	9.15E+09	9.15E+09	9.15E+09	9.15E+09	9.15E+09	9.15E+09
	Human	1.18E+08	1.18E+08	1.18E+08	1.18E+08	1.18E+08	1.18E+08
	Livestock	2.64E+09	3.26E+09	4.89E+09	6.52E+09	6.52E+09	8.15E+09

Table B.2 Monthly, directly-deposited, fecal coliform loads in the Gills Creek impairment. (Continued)

Reach	Source	Jul (cfu/day)	Aug (cfu/day)	Sep (cfu/day)	Oct (cfu/day)	Nov (cfu/day)	Dec (cfu/day)
1	Wildlife	5.87E+08	5.87E+08	5.87E+08	5.87E+08	5.87E+08	5.89E+08
	Human	2.08E+08	2.08E+08	2.08E+08	2.08E+08	2.08E+08	2.08E+08
	Livestock	1.88E+10	1.88E+10	1.50E+10	1.13E+10	9.12E+09	6.08E+09
2	Wildlife	2.42E+09	2.42E+09	2.42E+09	2.42E+09	2.42E+09	2.42E+09
	Human	7.98E+07	7.98E+07	7.98E+07	7.98E+07	7.98E+07	7.98E+07
	Livestock	8.24E+09	8.24E+09	6.60E+09	4.95E+09	3.99E+09	2.66E+09
3	Wildlife	1.74E+09	1.74E+09	1.74E+09	1.74E+09	1.74E+09	1.75E+09
	Human	1.71E+08	1.71E+08	1.71E+08	1.71E+08	1.71E+08	1.71E+08
	Livestock	3.92E+10	3.92E+10	2.99E+10	2.06E+10	1.94E+10	1.05E+10
4	Wildlife	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09
	Human	1.41E+08	1.41E+08	1.41E+08	1.41E+08	1.41E+08	1.41E+08
	Livestock	1.92E+11	1.92E+11	1.44E+11	9.66E+10	9.59E+10	4.84E+10
5	Wildlife	6.03E+09	6.03E+09	6.03E+09	6.03E+09	6.03E+09	6.03E+09
	Human	2.37E+08	2.37E+08	2.37E+08	2.37E+08	2.37E+08	2.37E+08
	Livestock	2.68E+10	2.68E+10	2.14E+10	1.61E+10	1.32E+10	8.79E+09
6	Wildlife	1.45E+10	1.45E+10	1.45E+10	1.45E+10	1.45E+10	1.45E+10
	Human	1.51E+08	1.51E+08	1.51E+08	1.51E+08	1.51E+08	1.51E+08
	Livestock	1.80E+11	1.80E+11	1.36E+11	9.25E+10	8.97E+10	4.69E+10
7	Wildlife	8.32E+09	8.32E+09	8.32E+09	8.32E+09	8.32E+09	8.32E+09
	Human	7.77E+07	7.77E+07	7.77E+07	7.77E+07	7.77E+07	7.77E+07
	Livestock	1.00E+10	1.00E+10	8.02E+09	6.01E+09	4.89E+09	3.26E+09
8	Wildlife	8.48E+09	8.48E+09	8.48E+09	8.48E+09	8.48E+09	8.49E+09
	Human	1.13E+08	1.13E+08	1.13E+08	1.13E+08	1.13E+08	1.13E+08
	Livestock	7.50E+09	7.50E+09	6.00E+09	4.50E+09	3.63E+09	2.42E+09
9	Wildlife	9.15E+09	9.15E+09	9.15E+09	9.15E+09	9.15E+09	9.15E+09
	Human	1.18E+08	1.18E+08	1.18E+08	1.18E+08	1.18E+08	1.18E+08
	Livestock	8.15E+09	8.15E+09	6.52E+09	4.89E+09	3.95E+09	2.64E+09

Table B.3 Existing annual loads from land-based sources for Gills Creek impairment.

Source	Good Pasture (cfu/yr)	Bad Pasture (cfu/yr)	Cropland (cfu/yr)	Woodland (cfu/yr)	Urban/ Developing (cfu/yr)
Pets					
Dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+14
Cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.01E+08
Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.68E+14
Human					
Failed Septic	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.04E+13
Livestock					
Dairy	7.84E+14	1.25E+15	6.08E+15	0.00E+00	0.00E+00
Beef	4.73E+14	1.82E+14	0.00E+00	0.00E+00	0.00E+00
Horse	2.69E+13	1.11E+13	0.00E+00	0.00E+00	0.00E+00
Goat	1.46E+10	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	1.28E+15	1.44E+15	6.08E+15	0.00E+00	0.00E+00
Wildlife					
Raccoon	5.11E+13	2.61E+13	5.07E+13	3.34E+14	6.95E+13
Muskrat	2.66E+13	1.13E+13	3.99E+13	1.73E+14	6.93E+13
Deer	8.10E+11	1.98E+11	3.09E+12	3.97E+13	1.04E+11
Turkey	5.76E+08	5.90E+07	4.99E+08	1.49E+10	0.00E+00
Goose	8.65E+09	3.67E+09	1.30E+10	5.64E+10	2.26E+10
Duck	7.79E+07	3.31E+07	1.17E+08	5.08E+08	2.03E+08
Unquantifiable	7.85E+12	3.76E+12	9.37E+12	5.47E+13	1.39E+13
Total	8.63E+13	4.14E+13	1.03E+14	6.02E+14	1.53E+14

Table B.3 Existing annual loads from land-based sources for Gills Creek impairment. (Continued)

Source	Farmsteads (cfu/yr)	Livestock Access (cfu/yr)	Loafing Areas (cfu/yr)	Golf Course (cfu/yr)	Hay/Grass (cfu/yr)
Pets					
Dogs	9.22E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cats	2.75E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	9.22E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Human					
Failed Septic	5.27E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock					
Dairy	0.00E+00	3.64E+13	4.47E+14	0.00E+00	0.00E+00
Beef	0.00E+00	1.26E+13	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	3.98E+10	0.00E+00	0.00E+00	0.00E+00
Goat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	0.00E+00	4.90E+13	4.47E+14	0.00E+00	0.00E+00
Wildlife					
Raccoon	2.14E+12	3.41E+12	8.07E+11	5.12E+11	7.54E+13
Muskrat	5.51E+10	1.23E+12	1.43E+11	5.18E+11	3.63E+13
Deer	5.93E+09	4.14E+10	1.30E+09	3.59E+09	1.27E+12
Turkey	0.00E+00	2.35E+06	2.60E+05	2.56E+06	9.04E+08
Goose	1.79E+07	4.02E+08	4.67E+07	1.69E+08	1.18E+10
Duck	1.62E+05	3.62E+06	4.21E+05	1.52E+06	1.06E+08
Unquantifiable	2.20E+11	4.69E+11	9.51E+10	1.03E+11	1.13E+13
Total	2.42E+12	5.16E+12	1.05E+12	1.14E+12	1.24E+14

Table B.4 Existing annual loads from direct-deposition sources for Gills Creek impairment.

Source	Fecal Coliform Load (cfu/yr)
Human	
Straight Pipes	4.72E+11
Lateral Flow	1.30E+09
Total	4.74E+11
Livestock	
Dairy	8.49E+13
Beef	2.94E+13
Horse	9.29E+10
Total	1.14E+14
Wildlife	
Raccoon	1.57E+12
Muskrat	1.77E+13
Deer	2.27E+10
Turkey	8.52E+06
Goose	3.13E+09
Duck	4.28E+07
Unquantifiable	1.91E+12
Total	2.12E+13

GLOSSARY

Note: ***All entries in italics are taken from USEPA (1999).***

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal waste water treatment plants.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs are paid by the producer (s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also* ***Respiration****.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always result in the same output.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Empirical model. *Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an* *observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Hyetograph. *Graph of rainfall rate versus time during a storm event.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff which travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished. (40 CFR 130.2(g))*

Loading capacity (LC). *The greatest amount of loading a waterbody can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those which restore, enhance, create, or replace damaged ecosystems.*

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's median test. A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nonpoint source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. *Model that approximates a solution of governing partial differential equations which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.*

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular land use segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/Staged approach. *Under the staged approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The staged approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA Section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for* *example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25^{th}, 50^{th}, and 75^{th} percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50^{th} quartile is also known as the median. The 25^{th} and 75^{th} quartiles are referred to as the lower and upper quartiles, respectively.

Raw sewage. *Untreated municipal sewage.*

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Septic system. An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Simulation. *The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also **Domestic wastewater**.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based effluent limitations (WQBEL). *Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.*

Water quality-based permit. *A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

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